TIGHT BINDING BOOK

AUTOBIOGRAPHY OF EARTH

by

John Hodgdon Bradley

AUTHOR OF "PARADE OF THE LIVING"

"*Everything in nature is engaged in writing its own history.*" EMERSON

New York

Coward-McCann, Inc.

Fourth Impression

Printed in the U.S.A.

For the Davids Who Sometime
Lift Up Their Eyes Unto the Hills

Contents

AUTOBIOGRAPHY OF EARTH

I

The Cosmic Plan

THE dream of peace on earth is strongly rooted in the human heart, but it was not in the mind of the architect when he planned the theater of the world, nor of the director when he cast the players for their several rôles. The original plan that terrestrial history shall unfold with turmoil has never suffered any significant alteration. The dead earth over which the pageant of life has streamed these many eons is dead only to the eye that does not see it as it really is. Through the ages conflict has marked the sojourn not only of plants and animals, but also of the clod beneath them.

Man does not normally sense the war that rages beyond the walls of his ego. When he turns to the night sky full of stars, to the mountains ranging quiet and vast against the horizon, he is filled as likely as not with serenity. Poets sing endlessly of peace in woodland glades, of tranquillity in the slow moving river, of such satisfactions in the world of nature as their own world has denied them. But nature, alas, is as troubled as the human soul. The

emotional chemistry that enables men to discover in her agitated heart surcease from their own agitations is a blessing sprung from other seed than reason.

Yet it need not be despised by those who go abroad with a more critical eye. The human mind has many compartments, and the calm that comes from contemplation of beauty need not be destroyed by a knowledge of that which lies deeper than beauty. And despite a certain damage to the prideful ego, there is something salutary in knowing that the drama of human life is but an infinitesimal fragment of the drama of the universe. Men may forget the pounding in their hearts when they listen to the throbbing of nature.

Since a very early age in human affairs there have been those who have regarded the earth not solely as a spectacle of beauty to ease the torments of living; not casually as a mere abode; not merely as a mirror wherein they may see the reflection of their own moods; but as a drama written in a foreign tongue and challenging an attempt at translation. The earth like all else in nature has written its own history, a dramatic story whose major themes are already known through the collaborative efforts of many translators.

Out of the mists that shroud the earlier thought of the human mind have come ideas about the earth

which can scarcely be called exact transcriptions of the earth's story. Centuries before the Christian Era, scholars indulged in a little careful observation and much carefree speculation on the origin, history, and architecture of the globe. Most typical were the weird cosmogonies of both Oriental and Greek philosophers, molded largely from figments of mythology and religion. An early and characteristic view was that of Hesiod who held that the world emerged from a primitive chaos; first the heavens, then the mountains and the oceans, and finally (a trifle belated) the gods. Even the more practical Romans preferred the poetic rather than the scientific approach to nature. As late as the first century after Christ, Lucretius elaborated the prevailing view of a hollow earth, filled with rivers of night, with awesome gorges, cliffs, caverns, and a wild wind that struck fire from the rocks. Such beliefs showed feeling for dramatic conflict as depicted in the world of the philosopher's imagination. The drama of the actual world played to an indifferent audience.

It cannot be denied that ancient speculative conclusions do in some cases broadly coincide with later beliefs reached through the slower, more difficult pathways of inductive reasoning. There are those who like to think that when an ancient speculator happened upon an idea whose essential truth was

later verified by the mechanics of scientific technique, he did so through some superhuman power of insight. They are apt to overlook the fact that many of his other speculations seem absurd. And the probability that fancy, roaming widely over a field of thought, will innocently encounter an occasional truth, is easily disregarded by those who enjoy the titillations of mysticism and who prefer the sky of their thinking to be flecked with clouds.

Such names as Aristotle, Strabo, and Seneca linger in the history of earth science because these men did at times seek to make the earth give up its own story. Yet even the sound contributions of such men were fragmentary, disconnected, and interlarded with myth. The simple truth is that although the ancient world held some of the most cultivated men who ever lived, although thought was for long periods free from the opposition of church and public opinion, the temperament of the people was not right for the laborious and often dull exertions whereby alone the facts of nature may be discovered. Literature and art could grow in such a soil, but science had to wait until humanity was more generally willing to work for the answers to its questions.

The wait was long. Collapse of the Roman Empire raised clouds of war, revolution, and intol-

erance that all but suffocated learning in the civilized world. Culture sneaked into the recesses of monasteries, but such science as gained these havens lay for centuries abandoned. The Arabs, who rescued some of the old learning from oblivion, were curious enough to expand it through their own investigations. They enlarged the sciences of mathematics, astronomy, medicine, and biology, but paid little attention to geology. Not until the Renaissance did earth science, after languishing a thousand years, begin to grow. And not until the nineteenth century did it break through the crust compounded of controversy over the obvious, ecclesiastical opposition, and footless speculation. Men finally began to see the earth as a record of the operation of immutable laws. Only then did they begin to decipher the hieroglyphs of time.

II

Among other things they began to suspect that Bishop Ussher had been moved more by piety than by a thirst for knowledge when he calculated that the curtain was first raised in 4004 B.C. When at the close of the eighteenth century, James Hutton demonstrated how the past history of the earth might be understood through the study of what is

happening to it today, the way was open to a verifiable conception of its true antiquity. It soon became apparent that any attempt to measure precisely the age of the earth in years is not less absurd than would be the attempt to measure the Pacific Ocean in pints.

It is difficult to imagine the time that has passed since the sequoia trees of California were seedlings. Yet the few thousand years through which these oldest living things have endured is but a moment in geologic time, and has added scarcely a wrinkle to the furrowed face of earth. Discovery of the tomb of Tut-Ankh-Amen fired the public mind with forgotten glories of man's past; yet when seen against the background of the earth's past, King Tut appears a modern monarch, and the few tens of centuries between him and us fade into insignificance.

Despite a calm and apparently immovable expression, the earth has seethed with conflicts since the beginning of its existence as a separate entity in the solar system. These conflicts, though vast and relentless, progress so slowly that the casual eye does not see them. For many years poets have sung of the everlasting hills, of the permanency of their physical environment. With the advance of geologic science it has become clear that the hills are not

everlasting, that some day the highest mountain peak will crumble and fall away, perhaps to rise again at a later date. Whole mountain ranges are known to have been built and destroyed in but a small fraction of geologic time. And as it is with the mountains, so it is with the rest of the earth. What we see today was different yesterday and will be different tomorrow. Nothing endures.

If we could return to our favorite haunts in the mountains or on the seashore after five thousand years, we should probably detect very little change. At most our trout lake might be choked with sediment or drained by a river. We might find that the stream which once flowed into the ocean a half mile from our seaside bungalow, now entered the ocean over the very site of the bungalow. We might even observe, if the house stood on a low, wide beach, that its site was now under the water half a mile from shore. But in the larger features of the landscape we should detect little change. Despite the unremitting attack of rain, frost, snow, and other agencies that gnaw at rocky eminences, the mountains would probably not be conspicuously altered. The general configuration of the coast would be much as it was before.

If instead of five thousand we should return five million years from now, we might be startled by the

changes we should see. The mountains might be worn down to mere stumps or even to a plain with no remnant of their former grandeur. The sea might have advanced upon the land so that broad regions once dry would now be drowned. Strange plants and animals might also inhabit the land, and in the water might be creatures vastly different from those of today. Even our own descendants might appear so different from us that we should scarcely recognize them as human beings. The student of earth history knows that such changes have occurred again and again in the past, and does not know why they should not continue to occur in the future.

The earth did not begin to record its history until after it had acquired an atmosphere and an ocean. The salt in the sea is brought there by rivers from the land; in the beginning all seas were probably fresh. Geologists have calculated the age of the oceans on the basis of the rate at which salt is now being supplied by rivers. As early as 1715, Edmund Halley suggested this possibility, but not until 1899 had sufficient data been accumulated to make a computation possible. In that year Joly, the British physicist, divided the estimated amount of salt in marine water by the estimated amount contributed each year by streams, and calculated that the oceans were 97,600,000 years old. Other computations

have since been made, and most of them allow the sea the ripened maturity of something like one hundred million years.

Even this figure is a palpable understatement. Continents stand higher today than they have stood through most of the past, and consequently rivers are more numerous, more powerful, more laden with salt dissolved from the lands they drain, than formerly. The present rate at which salt is being carried to the sea is too high to be taken as an average of all past rates, so that an estimate of the age of the oceans made from it must be too low. And there is no way of learning the rate at which rivers of the past have added salt to the oceans.

Even if there were a way of ascertaining the full age of the sea, we should still be compelled to guess at the age of the rock body of the earth which was old before the sea was born. A formative era when the globe was built of ejecta spewed from the parent sun is not recorded in accessible portions of the earth's crust, but it must have preceded the geologic eras revealed in the rocks after the coming of atmosphere and water. Its duration, according to astronomers, may well have been half a billion years. One hundred million years is long enough to paralyze the imagination, but not long enough even to

suggest the antiquity of the oceans and the venerable basins wherein they rest.

In addition to salt, rivers carry great quantities of sand and mud from the land to the sea. Each year untold millions of tons of rock waste find a resting-place at the mouths of the world's rivers. Each year the Nile alone deposits upon its delta over fifty million tons of rock débris. Yet we may spend our lives on the bank of a river and observe no appreciable widening of the valley. Rivers do widen their valleys, but so slowly that the brief span of a human life is a far from adequate measure. They not only widen their valleys, but they eventually reduce great tracts of land toward flatness. At the present rate of river wear, the widening of the Mississippi valley at St. Louis must have taken at least one million years. The flattening of the entire area drained by the Mississippi will require a much longer period, perhaps tens of millions of years. There is good evidence in the rocks that rivers of the past have repeatedly worn large areas of land nearly to flatness, so that the earth as indicated in the careers of its rivers must have been born considerably before the orthodox 4004 B.C.

In the course of earth history both rivers and other agencies of land destruction have piled vast heaps of rock waste not only in the oceans but in

the shallow basins of sea water that have repeatedly encroached on the continents. Such deposits have been consolidated, uplifted, and preserved. The so-called sedimentary formations have accumulated in this fashion to a total thickness of more than sixty-five miles. The rate of deposition was so variable and the years that slipped by during the process were so many that any guess at their number must be absurd.

When the modern geologist turns to the mountains he finds abundant evidence that they were built with almost inconceivable slowness. Most convincing, perhaps, are certain rivers that hold their courses athwart regions of uplift, cutting into the mountains as rapidly as they rise. Such a stream was the Columbia, which flowed over a region destined to be elevated into the Cascade Mountains. While the mountains rose the river cut into them with almost no deviation from its original course. Today the Columbia flows placidly through the heart of the Cascade Range, nearly as it flowed before the mountains existed. We know that rivers cut their channels very slowly, so we must infer that mountains traversed by such persistent streams as the Columbia must have risen equally slowly. Yet in the history of the earth lofty mountains have been repeatedly built and worn away. The time involved cannot be

determined in years, but it must have been long—so long that the imagination cannot grasp its significance.

Now that men do not generally interpret the fossil remains of plants and animals as abortive attempts at creation fathered by the devil, they may read in these relics the story of antiquity. We know that the plants and animals of today are not noticeably different from those described in the earliest human documents. Five, ten, fifteen thousand years may pass with no conspicuous alteration in the general aspect of living creatures. Yet striking changes have occurred. Before man the dinosaurs ruled the earth, and before the dinosaurs, various races of fishes and lowly marine animals struggled for world dominion. Whole dynasties of creatures have risen to dominate the seas and lands of the past only to fall into extinction and to be followed by other dynasties. Even the oldest fossils known suggest that a long ancestry is lost in the confusion of the remoter past. These facts prove that the earth is old, so old that the brief flash of a year or a century loses all meaning.

There are approximately forty methods of estimating the age of the earth. All but one of these deal inadequately or inaccurately with the missing intervals so abundant in the geologic record, and

consequently lead to obvious understatements. The one method that seems capable of accurately measuring something like the totality of the earth's antiquity has come from the study of radioactivity. A few elements in nature, stirred constantly by a slow turmoil of their atoms, are continuously changing from one form to another. Uranium, for example, passes into radium, and ultimately after many alterations, into helium and lead which are stable products. Such elements are unaffected by heat and pressure; nothing known can disturb the rate or the character of their transformations. They stand alone in nature, independent of outside influences.

The rate of the evolution of radioactive elements has been accurately apprehended through experiment. The age of a rock containing uranium can be calculated from the amounts of uranium and lead it contains. Since the time required to generate the lead is known, sufficient data may be had to estimate the age of the specimen. Geologic time measured by this method stretches to 1,850,000,000 years. When this is enhanced by the probable half billion years of the Cosmic Era, 2,350,000,000 B.C. emerges as the generally reasonable but far from exact date when earth was born of the mother sun to embark upon the harassed career recorded in its body.

III

Human folly is not the only phenomenon in nature that repeats itself. The whole universe pulsates in a monotonous rhythm. Time is a shoreless ocean, and its waves though endlessly rolling roll endlessly alike. The conception of perpetual change in nature was vaguely expressed by some of the ancient and medieval philosophers, but the plan beneath the universal flux failed to emerge. One of the chief aversions of the human heart is change. Perhaps that is why the doctrine of evolution in plants and animals, although conceived at an early date, languished until the middle of the last century when it fell like acid from the pen of Charles Darwin upon the reason of thinking men. Now it is known that the ebb and flow so clearly demonstrated for the races of living creatures moves in their physical environment as well.

The concept of evolution has grown in nearly every branch of natural science, and with it the belief that evolution, whether of an atom, a man, a planet, or a star, travels along definite lines. That these lines are not straight but decidedly curved, and in some cases nearly circular, is one of the most inclusive and significant generalizations of modern thought.

When Tacitus said that "in all things there is a

kind of law of cycles" he could not have been definitely aware of any but such obvious cycles as day and night, summer and winter, birth and death. Modern science has discovered new evidence of the slavery of matter and energy to cyclical patterns. Many astronomers believe that the colors of stars indicate various temperature conditions, that every star in the firmament lies in some stage of a cycle of temperature change. There is evidence for the belief that a star originates from a relatively cool diffuse nebula; that, through gravity, its gas particles are drawn more closely together until the young star glows red and eventually yellow; that with adulthood it shines blue-white; that later heat is dissipated, the star reverses the order of its color changes, and returns in old age to a condition similar in many ways to that of its youth.

The spectroscope shows an undoubted correlation between the color and the chemical constitution of stars, so that there seems to be a parallelism between the evolution of the elements of which stars are built and the stars themselves. What is known about the disintegrative evolution of the heavy radioactive elements supports this thesis.

Similarly, many of the processes by which the earth has been molded have rolled through time with untiring repetition. Not aimlessly but in ac-

cordance with a great plan have the cycles of earth history turned, cycles of dramatic conflict as vast as the time through which they have endured, and compared with which the pulsations of human fate seem trivial.

Fundamental among terrestrial conflicts is the cyclical alteration of rocks. The oldest rocks undoubtedly congealed from a liquid not unlike the lavas that pour from the mouths of active volcanoes. We have no record of them because they are buried beneath younger formations, but we do have rocks of the same genre formed at a later date. These are the igneous rocks of many places and ages, the parents of all other rock types. Nearly all the ninety-odd chemical elements known on earth have been found in these most primitive and at the same time most complicated of rocks.

Exposed at the surface of the earth, the igneous rocks suffer the attack of the cohorts of physical destruction, an army in whose ranks march such redoubtable warriors as frost, wind, moving ice, and running water. With these come the agents of chemical decay, weakening the rocks from within so that they may be more easily blasted from without. No rock can forever withstand such an attack. The forces of geologic destruction do not know defeat.

The products resulting from the disruption of

the igneous rocks are scattered far and wide. Some find rest on the surface of the land as loose earth and gravel, a mantle for the bony framework of the continents. Some are dissolved and dissipated by the underground water and by the rivers; some are carried as mud, sand, and gravel to lakes and ocean basins. During transportation the mineral and rock particles are rearranged according to weight and size, so that the resulting deposits usually consist of rather well defined layers of well sorted débris. The heavy materials are separated from the light, and the coarse from the fine. Such waste may later be compacted and cemented into the simpler sedimentary rocks so widely exhibited at the surface of the earth.

Nature is not content with forming simple sedimentary rocks from complex igneous rocks. She tires of simplicity. She may pour hot lavas over the unconsolidated clays and gravels of the mantle, causing the particles to weld together and new compounds to develop. She may cause hot liquid rock to squeeze between the sheets of sedimentary formations, baking and partially recrystallizing them. She may buckle the surface and profoundly alter the form of all the materials involved. Thus do the metamorphic rocks arise from the alteration of pre-

existing formations. Intensity of the metamorphic process destroys the characteristic simplicity of sedimentary strata.

Metamorphism is fundamentally a process of crystallization and very similar to the process whereby the igneous rocks were originally born from a mother liquid. When sedimentary rocks are subjected to great heat and pressure they are often sufficiently altered to resemble igneous rocks. Thus the cycle of evolution is completed; after many changes the materials of the earth's crust approach their original condition. Over and over this cycle has turned—through nearly two billion years of history. It began when the earth acquired an atmosphere and it will end only when the atmosphere disappears, or when such a catastrophe as brought the solar system into existence returns to destroy it.

IV

Not only the substance of the earth but also the expressions on her face pass through repeated cycles of change. The concept of erosion cycles is perhaps the greatest contribution of American physiographers to earth science. It has long been known that rivers change the appearance of the lands, but not until comparatively recently has science recognized the

orderly cycle of change resulting from the long continued activity of rivers in any given locality.

Streams, like men, pass through stages of infancy, youth, maturity, and old age. In infancy a stream is short and steep, and flows in an infant valley: a gully or a ravine. The valley grows longer, wider, and deeper with time until youth is reached. The divides between youthful valleys are broad, but the valleys themselves are relatively narrow. The streams flow vigorously, in many cases with waterfalls and rapids. Much of their work lies before them. The country they drain is also youthful and it is destined to be profoundly altered before the streams grow old. With maturity the young streams become longer, their gradients more gentle, their valleys wider. Tributaries increase in size and number to form a branching pattern over the land. The country is reduced from the smooth upland of youth to a group of irregular hills and ridges. With time the gradients of the streams approach nearer and nearer the horizontal, until the water flows in sluggish meanders through low, wide valleys separated by low divides. The streams and the land have grown old.

Like men in their march from infancy to senility, rivers and the lands they drain do not return to the exact condition of their youth. Although the cycle

is not perfect, the old age of a river-carved terrane is remarkably reminiscent of youth. Both are relatively flat and smooth; both are characterized by few main streams and many undrained lakes and marshes.

Death dogs the heels of old age in the life cycle but not in the erosion cycle. Before rivers have reduced their lands to sea level so that marine water can creep in and drown the country, they lose their power to cut and carry away any more material. They turn instead to building up the region which for so long they labored to destroy.

And too, a region is seldom allowed to evolve regularly from infancy to old age, because earth movements continually change the gradients of rivers, steepening and rejuvenating some, flattening and prematurely aging others. Although the cycle is seldom completed, although some parts are repeated and others eliminated, the tendency to a rotatory sequence of change is present in the rivers and their lands today just as it has always been present since water began to flow from the highlands to the sea.

Not only the changes in the substance of the earth and in the expression on its face, but also those deep-seated changes in its body which control the major events of its history, seem to adhere to a

cyclical pattern. Even the casual observer of earth features can see that many formations now crumpled and broken were once flat and continuous. Measurements on the rocks of the Alps show a shortening in the earth's circumference of more than a hundred miles. In many other places the circumference has been considerably shortened, so it must follow that the diameter has likewise been shortened.

Such evidence points to a progressive shrinkage of the globe through time. For many years the accepted explanation of this shrinkage was cooling and consequent contraction of the materials constituting the deep interior. But cooling no longer seems an adequate cause for such a great contraction as is now known to have occurred. Besides, it is not certain that the earth is cooling. Increasing knowledge of radioactivity is leading some scientists to believe that perhaps the earth has actually gained more heat through the disintegration of unstable elements than it has lost through radiation. In the face of modern knowledge the scientist must look to the tremendous pressures in the deep interior as the prime cause of shrinkage. Under these pressures materials may well suffer progressive molecular rearrangements which result in new compounds of greater density and less volume. Thus as age crept on, the earth may have grown denser and smaller.

But it does not yield easily to inner stresses. The study of earthquake waves has shown that the body of the globe is in a state of elastic rigidity, and resists the forces that are ever struggling to decrease its volume. So unrelenting and powerful, however, are the forces of concentration that they periodically overcome the inherent strength of the earth and throw the surface into wrinkles. The yielding of surface formations has proceeded through time in a sort of vicious cycle, epochs of resistance alternating with epochs of surrender. The recognition of this cycle is the basis for the division of recorded time into geologic eras. Each era is set off by a world-wide weakening and yielding of the crust under the stresses of shrinkage. Smaller time divisions are demarked in similar fashion by less intense and less widespread convulsions.

The interplay of surface and subterranean cycles makes yet another cycle which eclipses because it includes all others. The forces of erosion, by leveling lands and filling ocean troughs, have forever striven to reduce to flatness the irregularities of the surface. Earth movements have periodically thwarted erosion by crumpling and elevating rocks in weak zones. Earth history has been a long struggle between these two contenders, the pendulum of success swinging now toward one, now toward the other.

Since the earth yields only periodically to the stresses of shrinkage, there are long intervals when erosion can quietly pursue its destructive work. Slowly the rain and the rivers, the wind and the glaciers, remove the rocks from high places and deposit them in the depressions; slowly the spreading seas creep over the continents. If the process were allowed to proceed to its logical end, the earth would become a nearly perfect sphere and a universal ocean would swallow all the lands. But always before this happens surface irregularities are renewed by earth movements, if only to be destroyed again by the erosion that always follows.

V

For nearly two billion years has this greatest of all earthly conflicts raged. Although begun many eons before the curtain was raised for the drama of life, it is destined perhaps to continue for as many eons after it is lowered. The drama of life is indeed but a special and perhaps an evanescent expression of the conflicting forces that have marked the sojourn of earth through time and space. Living creatures somehow rose from the clod and weathered the vicissitudes of many long ages to the present.

Their fortunes and the fortunes of the surface of the earth have been one.

The Darwinian concept of change in the organic world stressed the origin of new species, but neglected the ancient patterns on which new species have been unvaryingly erected. The monotonous business of eating, growing, reproducing, and dying is the chief activity not only of individual plants and animals but of species as well. Haeckel and Hyatt long ago called attention to the fact that changes in the early life of an individual organism are essentially the evolutionary changes already undergone by the race to which the individual belongs. Living creatures, in the words of Huxley, climb their family trees. This easily demonstrated principle, known technically as "recapitulation," is firmly built into modern biologic doctrine.

An old snail shell may faithfully record all the changes that life brought to the creature who inhabited it. At the apex of the coil is the little shell that first guarded the naked bit of living jelly from the world outside. The enlarging conch preserves the story of youth. A scar may tell of the jab of an enemy; crowded lines of growth may recall years that were lean. Farther along is the shell of full maturity with the knobs and spines that constitute the molluscan version of sex appeal. Finally, where

the coils give way to the aperture, is the shell of old age, simple like the shell of youth, but degenerate as is always the simplicity of second childhood. Step by step the snail has written his autobiography in his skeleton.

And in similar fashion, many shelled animals write not only their own biographies but the biographies of their respective races. Nautilus, for example, is the last of an ancient line of marine shell-fish. The vigor with which he tears the nets of fishermen today is but the final flickering of a flame that blazed brightly through the early periods of the Paleozoic Era. In the beginning the nautiloids wore straight, conical shells. They grew to many feet in length and pressed their ruthless mastery into every cove of the aqueous world. With time their shells curved, first in gentle bows, later in loose coils, still later in tight coils, finally in coils whose outer whorl enclosed all the inner whorls. In growing from egg to maturity, the living nautilus passes through most of these stages, each stage comparable to the adult condition of some remote ancestor. To break back the shell of a nautilus, whorl by whorl, is to turn backwards the pages of history, not only the brief life history of the specimen in hand, but of the entire race of nautiloids. Every living nautilus thus writes the epitaph as well as the biography

of his line, for although the past held ample glory, the future is darkened by the shadow of extinction.

Backboned animals do not record their own past or that of their race so well as the shelled invertebrates because their entire skeleton changes constantly with growth. Yet many of them reflect some of their racial history. In the developing body of a man a story unfolds. Even if man may some day learn to keep the beast from his spirit, he can never take the beast from his flesh. He is a placental mammal no less than horses, elephants, cows, cats, beavers, whales, and apes. Like them, he suckles his young, and has a backbone, warm blood, hair, separate chest and abdominal cavities. Furthermore, when the human embryo is four weeks old it has a tail, but not the tail of a mammal. It is broad and flat like that of a fish. At the sides of the throat are four pairs of slits with arteries and nerves like those in the heads of certain fishes. The heart, too, has but one auricle and one ventricle; the urinal and rectal passages end in a common receptacle with but one opening to the outside. So fish-like is the early human embryo that biologists see in it reflections of a day when man's forbears went on fins through a world of water. The human embryo testifies to man's animal origin quite as eloquently as his mature

body proclaims him an animal still, however far his spirit may have traveled toward Olympus.

The racial history of any creature obviously comprises a longer and more intricate chain of stages than does the life history of any individual, even one as complicated as a man. Naturally, all the events of millions of years cannot be summarized during the span of one brief lifetime. Racial history is often distorted because of the speed with which it must be retold in the rapidly growing individual. Many stages may be omitted, others may be altered by recent adaptations, so that life history does not always give a true picture of racial history. Yet many thousands of plants and animals are known to summarize during their individual lives the outstanding events of their evolution.

An equally obvious principle has received less emphasis, that the later life of an individual prophesies the destiny of its race. The paleontologist, who knows some of the history of the remoter past, can see that maturity, senility, and death are almost as inevitable for races as for individuals. He reads the fossil record of the repeated rise and fall of plant and animal dynasties. He sees that the chief distinction between race and individual is that the racial cycle may be very long, whereas the individual

cycle is very short. Unhappily, this is a distinction without a difference.

In one way or another nature imposes on the entire universe her inexorable injunction that dust must return to dust. Man, whose fondest dream is freedom, must dwell in a world of whirligigs, wherein stars and atoms, races and individuals, mice and men, must move in circles with monotonous repetition. The only reward for the energy expended is to arrive in the end at the starting point.

The basic handicap to man's dreams is that he is an animal, subject to the laws that govern all flesh. Like other animals, he climbs his family tree, whether he finds it edifying to do so or not. How strong are the bonds that hold him to his place in nature? How capable are his mind and spirit to give substance to his dreams? What are his chances, in descending the family tree, to avoid the grave that gapes at his approach?

VI

Obviously, nothing can be done about the past except to study it for prognostications of the future. Little hope flowers from the study. The past is a graveyard tiered deeply with the bones of forgotten creatures. Races that were the uncontested masters

of the world for their day have followed one another in the unremitting march to oblivion. Life has offered but few sinecures to its devotees. The one-celled plants and animals, so plentiful today, have come up from the past essentially unchanged. Certain shellfishes, certain fishes and reptiles, are anachronisms in the modern world because they have long outlived others of their kind. They are decidedly exceptions; the usual price of life is death.

Those races that escape death for long periods may consist of recluses who shrink from the active arenas of competition and forego the joys of richer living for the joys of a longer life. But these comparative immortals must pay a price that may be worse than death. Invariably they are primitive or degenerate, because nature offers no other alternative to progress and death.

From the point of view of permanency, nearly all races have been failures. The more excellent the mastery of a set of conditions, the more positive has been the dissolution that followed a change of conditions. Although the inner vitality of a great race may flow quite independently of outward circumstances, it inevitably ebbs.

Man is the flower of a race whose vitality has ebbed. His nearest relatives are chattering their version of the swan song in the tropical forests of

Africa and the Orient. He himself is losing many of his physical endowments. His eyes do not see so clearly as before, his ears are not so delicately attuned, his nose is scarcely more than a bump on his face. His hands are growing weaker, his teeth have become more of a handicap than a help, and his upright carriage is a very definite hazard at childbirth. The formerly helpful appendix is at best a museum piece marked neither for utility nor beauty; at its worst it is an incubator of death. Except for the perfection of his brain, man is as humble an aggregate of organs as ever presumed to biological leadership.

With the help of science man's body will hold together for some time, but there is little hope that he may be able to sidestep the abyss that yawns at the roots of his family tree. From its dark depths he emerged, and into them he will probably return. Through ingenuity he will weaken some of the forces that drag him downward. Despite war and disease, he is increasing his numbers faster today than is any other mammal. The elaborate care he bestows on his young, the most helpless on earth, has enhanced their life expectation, weak as they are, beyond that of most other creatures. His growing ability to migrate to greener pastures, his unparalleled powers of discovery and invention will retard

the death that would soon overtake a less resourceful race. Yet in him are the germs of dissolution. There is no good reason to believe that man's body will not continue to change for the worse as the ages roll over him, until at last he, too, has met the universal fate of flesh.

But the regressive turn of human evolution may be expected to differ from that of any pre-existing race. The trilobite and the dinosaur ruled the earth for a duration of time compared with which man's dominance may well shrivel into insignificance. Yet, strong as they were in their long heyday, they were powerless to commute in any way the sentence of death that had been written into their destiny. They gained the glory of supremacy and the ignominy of extinction without the slightest ability to direct or even to perceive the course of either. The winds of fate still blow in the same direction, but man is the first mariner with a rudder for his life and an intelligence great enough to direct its use. Ultimately he will probably be forced to beach on the same old shore, but he can reach it with a beauty and a dignity hitherto unknown.

The hope of humanity lies in an organ that has seen service in the heads of countless creatures before him. With the slow growth of the brain came increased intelligence, and finally, in man, self-con-

sciousness. Lower animals have always been victims of their instincts, following them blindly whether they led to safety or to death. Man cannot escape the impulses that have blended with his blood as it flowed out of the past, but he can scrutinize them and control them. Thanks to his brain, he can do what no other creature has ever done: he can help shape his own destiny. He can do this with his brain as it is today, and happily so, because, by the tokens of biologic history, he can expect no better brain in the future. Man's great hope lies not in the development of better equipment, but in an extension of the use of the equipment he now possesses; not in a progressive physical evolution, but in an evolution of mind and spirit.

Nature has rigged him fairly well for the new venture. The instincts of self-preservation and reproduction have come to him from the past. Without them he would leave the earth before the turn of the century. If the first sometimes leads to war and the second to debauchery, it means not that the instincts are bad, but rather that man has not controlled their use with the power that has been given him.

The parental instinct, acquired much later in the history of the nervous system, has come to man in its finest form. If it leads at times to the enslave-

ment of a mother or the repression of a child, it is also the guardian of those spiritual values that make life worth living for creatures who can know something of love and beauty and truth. The herd instinct, last gained of all basic impulses, may lead to standardization, but it may also be the foundation without which civilization would crumble away.

No one can predict how far man will be able to use his intelligence to shape his own life. He is the latest and (if we are to accept his own estimate of himself) the greatest of living creatures. It is the pleasure of the complacent to hold man distinct from the rest of nature because of his unique advantages. Yet beyond the bluster of self-satisfaction, beyond the beauty of the most sublime human attainment, is the swirl of inexorable forces. Man is privileged to work toward an understanding of these forces and thereby toward more comfortable adjustments with them, but he is not privileged to control them. Human life has never been, can never be more than a small though special phase of the activity of the universe.

Earth history and human history are cogwheels enmeshed in the cosmic machine. They turn together. The songs men sing, the books they write, the pictures they paint, the social and mechanical devices they build, the wars they wage—all the

activities that make humanity what it is, and suggest with blended hope and despair what it might become—are inexorably geared to the earth. Knowledge of this relationship is the first requirement of a philosophy of man.

Were the story of the globe to be chronicled for some cosmic consciousness, the part that humanity has played in it might well be relegated to a footnote. But man, whom nothing charms so much as man, reverses the emphasis so that the larger story becomes the footnote, or at most a mere background for the events in his own history. Accordingly, the point of view of the following translation of the earth's autobiography will defer not a little to the favorite failing of the translator and his readers. The majestic conflict of terrestrial forces will be described both as a drama in its own right, and as a theater where man is protagonist of the play.

II

The Ocean Overhead

NOT so very distant as distance is reckoned in this day of the hundred-inch telescope and the Einsteinian imagination, is a land where the forces of erosion do not battle with the forces of upheaval. Indeed the forces of erosion do not there exist for lack of an atmosphere to give them birth. Scars of ancient upheavals are clear, but so far as anyone can tell, the depths are now as tranquil as the surface. Of all the regions bared to the prying eye of science, none is more surely quiescent than this one. There is no drama on the moon.

A few astronomers believe they have detected a lowly vegetable life and occasional traces of snow on the surface of the moon, either of which if certain would prove the presence of an atmosphere. Other astronomers have failed to see these signs. All may observe, however, that the forces engendered on earth by the atmosphere have obviously not touched the moon; that the chief features of the lunar landscape attest a virtual absence of air.

The skin of the beautiful lady whose face may

be discerned on the full moon's surface loses its enchantment when viewed through the realistic medium of the telescope. Like the Brobdingnagian matrons of Gulliver's adventure, the Lady in the Moon is sadly blemished. Suggestive of the ravages of smallpox are the pits that scar not her alone, but also much of the rest of the moon's expanse. One hundred thousand pock marks may be counted. Men have generally thought these the craters of extinct volcanoes, and a few astronomers still rest on this assumption. But the lunar craters, if craters they be, differ from nearly all mundane craters in being broad and shallow rather than narrow and deep. Other astronomers believe them the scars left by the bursting of rock bubbles filled with volcanic gas when the moon was seething with distempers. Still other, perhaps most astronomers, see in the pitted surface of the moon the result of a bombardment by large meteorites or small planetoids at some time before the surface froze to brittleness.

Whatever they may be, the cavities on the moon have stood for no one knows how long an eon with little change. No wind or running water have blurred their outlines. Nothing about them suggests the attack of those air-born marauders who continuously harass the surface of the earth. They stand as sharply delineated as the hard black shadows they

cast, which unlike earthly shadows are nowhere dissipated through the medium of an atmospheric screen capable of softening the glare of the sun.

No water is anywhere visible, and the broad flat areas once thought to be seas are now known to be plains. At the edges of one such plain rise the lunar Alps and the Apennines, the Caucasus and the Carpathians, with their thousands of strange gaunt peaks. Except in name they are like no mountains on earth. No frost has blasted them, no glaciers or torrents have softened their declivities. They look like jets of liquid rock that congealed at the instant of eruption. Five miles above their roots the lunar mountains rise, higher than most and steeper than any mountains on earth.

Men have dreamed of exploring this wasteland. Should they ever succeed in rocketing to the moon, they would doubtless find there a variety of diverting phenomena. After devising some method of controlling the internal pressures of their bodies to avoid bursting, after solving the problem of transporting sufficient oxygen to prevent suffocation, they might yet have difficulty in communicating with one another. Sound is impossible in a vacuum; neither the human voice nor the roar of a volcano could exist on the moon. With no dust or moisture to diffuse the sunlight the sky would look black, the stars

would shine both day and night, brightly and without twinkling. Daybreak and nightfall would come suddenly, with no intervening twilight. The sun would blaze in all its splendor, each day revealing the corona which earth dwellers may normally see only on the rare occasions of total eclipse.

During the nights of fourteen earthly days, temperature would sink well toward —459°F., the absolute zero of space. During the days of similar length, the light and heat from the sun would beat down unimpeded, but the heat might rebound in radiation before the surface grew warm enough to be comfortable. The climate on the moon would be at best a trifle rigorous. If the visitors from earth could withstand the diurnal variations in temperature, they at least would suffer nothing from storms. Without an atmosphere the moon is spared the fret of atmospheric disturbances.

All these spectacular differences between moon and earth result from the fact that the latter goes veiled under a mantle of air, whereas the former travels naked. The spherical shell we call the atmosphere is as much a part of the earth as the skin is part of an orange; as much a factor in its history as a portion of its anatomy. For eons the earth has been alive with conflicts bred in the air, and through them very largely she has become what she now is.

This ocean of air, whereunder men and mice and rocks travel the pathways of destiny, is reputed some fifty miles deep. At about that distance above the earth's surface must lie the vague horizon where the ever-thinning gases of the atmosphere give way to the emptiness of space. Like the more substantial ocean of water beneath it, the ocean of air is not uniformly heated. Its temperature is controlled very largely by the temperature of the surface whereon it rests, which varies widely from pole to equator and from season to season. Because the weight of air varies with its temperature, differing pressures grow in the body of the atmosphere and start currents in the lower regions. Water vapor is lighter than air; wherever it concentrates, the balance of pressures is further disturbed and other air movements are set in motion. The rotation and revolution of the earth further enhance the restlessness of the atmosphere. Thus it is that wind currents not unlike the water currents of the sea are born and nourished.

The upper reaches of the atmosphere, like the profounder depths of the sea, are comparatively free from turmoil. The storms of both these oceans do not wander far above or below the level where the two meet at the surface of the globe. The wispy cirri, highest of clouds, gather in temperate latitudes not far above the elevation of Everest. Near

this point the nature of the air abruptly changes. Above it temperature, which steadily declines away from the surface of the earth, declines no further. All rising air currents have cooled so much that they are unable to rise any farther. They move, if at all, horizontally. It is here that the stratosphere, or upper air, begins; where it ends no one surely knows.

It is largely the lower more turbulent portion of the atmosphere that has helped shape the essentials of terrestrial physiognomy. Through its constitution, as well as through its movement, the lower air is able to alter the rocks. Despite the fact that nearly four-fifths of the air consists of the inert gas, nitrogen, and as a result is chemically impotent, the atmosphere is yet chemically powerful because the remaining fifth consists chiefly of the active oxygen. Significant too is carbon dioxide gas, which accounts for only three ten-thousandths of the volume of the atmosphere, yet accomplishes a vastly disproportionate amount of geologic work. Of several other inhabitants of the air, water vapor alone has played any large part in the history of the lands.

This ocean of commingled gases on whose bottom we live is seldom sufficiently obtrusive to make us more than dimly aware of its existence. Yet its existence makes possible our own. Its oxygen allows our bodies to breathe and our hearth fires to burn.

Its carbon dioxide and water vapor weave a blanket that keeps us from frying by day and freezing by night. Without air rugged desolation would everywhere mark the continents. There would be no landscapes softened by soil and growing things, no wind, no rain, no rivers, no glaciers, no oceans; only that frosty quiet which in the living world is known as death.

To the inanimate constituents of earth the air brings an activity not unlike that of the life it brings to plants and animals, but an activity without beneficence. Destruction is the major gift of air to earth. If its regiments might ever advance unhindered, all rocks would slowly crumble away and disappear beneath the sea.

II

The origin of the globe is a vague event in history, and the early stages of its career as a separate entity in the solar system are shrouded in mist which the conflicting conjectures of scientists only make more dense. Scholars are rather generally agreed that the earth and its sister planets must have been born from the body of the sun after disruptions induced there by the gravitative pull of a passing star. They do not agree on what happened during the

half billion years that followed. According to one popular theory, the solar gas-bolt destined to become earth quickly cooled and condensed to a solid sphere about one-tenth the size of the adult planet. This nucleus grew by the influx of smaller bodies derived from the sun at the same time and in similar fashion.

With growth the earth gained enough gravity to hold the gases that constitute the atmosphere. The molecules of the heavier gases may well have been drawn to the earth core at an early date; perhaps they were present from the beginning. Heat generated by the impact of infalling solids must have liberated additional gases. Today all types of meteorites give off gas when heated; it is not unreasonable to assume that meteorites of the past did likewise. Pressures and the decay of radioactive substances in the growing core eventually developed enough heat locally to inaugurate volcanic activity. When this stage was reached, gases in sufficient quantities for an atmosphere were assured. Intense heat drives gas from nearly all known kinds of rock. When liquid rock began to rise to the surface of the earth through the throats of volcanoes, vast quantities of gas and vapor must have risen too.

Thus the atmosphere grew with the growth of the rock sphere beneath it. Water vapor increased until there was more of it than the air could hold.

Rain fell and made oceans of the primeval lowlands. When water came to the surface, life must also have come. The earth began to record its history. From then on through all the eons that followed, the surface of the earth suffered many significant changes, while the air above remained essentially the same.

Out of all proportion to its tenuous constitution is the vigor with which the air has waged its endless war against the lands. In one way or another the atmosphere contrives to loosen, break, and decompose rock materials with the aid of two-edged weapons that on one side cut chemically and on the other mechanically. The attack varies from place to place and from time to time, but it never ceases and it never fails.

The lives of many creatures from bacteria to men are dependent upon the success of the atmosphere in its conflict with the rocks. Land life would have been largely impossible if the air had failed to reduce to fragments the surface of the earth's tough rind. Atmospheric moisture carrying carbon dioxide and oxygen falls like the hand of death upon the rocks. That which it touches slowly rots away. Some minerals are dissolved and carried off. Others, hungry for oxygen, take their fill of that element until they are changed into new substances which are invariably bulkier and weaker than the original

minerals. Some bloat and grow heavy through uniting with water; others take on carbon dioxide and become the easy prey of decomposition. In one way or another the atmosphere brings decay to the superficial rocks of the earth, decay that produces soil and thus gives life to plants and animals.

When it freezes, water, unlike most other substances, expands about one-tenth of its volume. Ice is thereby less dense than water so that lakes and rivers freeze first at the surface. Only when low temperatures persist for a long period without a thaw do even the shallower waterways congeal to the bottom and slaughter the creatures who inhabit them. By allowing water the unique distinction of expansion on freezing, nature vouchsafes to her aquatic children the prospect of another Spring.

But such amenity extends no further than this. Physically as well as chemically nature is ruthlessly destructive of her inanimate creations. Rocks are powerless to resist the pressure of water freezing repeatedly in pores and fissures with a force that exceeds two thousand pounds per square inch. The tops of high mountains are characteristically a desolate waste of fragments hewn loose by the action of frost. Their sides, if steep and unguarded by vegetation, may be clothed with a drapery of frost-riven blocks, the "slide rock" familiar to mountain

climbers. Such accumulations, as well as banks of more finely pulverized materials, may be urged down slopes as sluggish earthen rivers through the persistent activity of frost and water in the interstices between the particles of rock.

On the great deserts of the world caravans must fight their way across two types of land. Seas of sand dunes undulating to all horizons alternate with the even more barren reaches of pebble-strewn plateau lands. No regions on earth are more desolate than the rock deserts which in the Sahara are known as "Hamada". So great is the variation in temperature over these wastelands that the thermometer may drop 80°F. or more between noon and nightfall. The explorer Livingstone was the first to report that whenever a very cold night followed a very hot day, the black lava rocks of the Sahara Hamada would rupture with a ringing reverberation resembling the crack of a rifle. Others confirmed his observation, and it became the belief that the vast Hamada owed its covering of angular stones very largely to the stress of alternating expansion and contraction in overheated rock.

More recently, however, belief in the blasting effects of diurnal variations in temperature has been shaken. It would seem that much of the phenomena formerly so explained could not exist without the

moisture which, even in desert lands, insinuates itself into the pores of rocks. In many areas where rocks are intensely heated each day and each night rapidly cooled, weakening stresses open avenues of approach for the potent agents of chemical depredation. Unequal expansion and contraction of the mineral grains, plus the cankerous operations of oxygen, carbon dioxide, and water, cause the surface portions of rocks to spall off in layers that resemble the concentric spherical shells of an onion. Ben Nevis in Scotland, Stone Mountain in Georgia, Half Dome in Yosemite National Park, and many other large rock bodies have been sculptured in this fashion; innumerable lesser examples exist wherever mountains lift their peaks into the air. Any rock so attacked is destined to become in the end but a formless heap of fragments, to be scattered willy-nilly at the whim of wind, running water, and gravity.

In ways such as these the atmosphere, merely by its presence through innumerable eons, and quite independently of the movements that forever agitate its lower reaches, has wrought great changes in the cuticle of the earth. Some of the most striking elements of mountain scenery have resulted from the blighting touch of air. Less conspicuous is the mantle of rock particles that covers much of the

skeleton of the continents. Many geologic agencies have joined in its production, but no others have worked so effectively as the agencies of the air. During all the eons of their existence they have quietly but steadily gnawed at the rocks. No other forces on the earth or in it have been more persistent; no others have been more significant in shaping terrestrial history.

III

Through its movement the atmosphere gains a different sort of power. The breeze that pleasantly fans our faces is sister to the wind that lays low our homes. Air swirling in tornadoes creates periodic havoc in the haunts of men, but it alters very little the broad earth whereon they live. Most of the geologic work of moving air has been accomplished by milder winds blowing more steadily and more frequently.

Dust and sand are by-products of all terrestrial conflicts. Glaciers grinding over their beds, rivers tearing at their channels, waves beating on a million miles of shore, volcanoes expelling untold tons of pulverized rock, add their litter to that produced by the corrosive touch of the air. By trafficking in such materials the wind becomes one of the most impor-

tant weapons used by the atmosphere against the land.

In temperate climates of abundant rainfall the pieces of rock constituting the mantle of the earth are more or less tightly sewn together by the roots of vegetation. Over the arid and semi-arid wastelands of the world the mantle is more loosely knit. There the wind is undisputed master. Even the gentler breezes may lift and carry dust for many miles, and more tempestuous storms may sweep along the larger grains of sand and gravel.

When in 1883 Krakatoa blew two-thirds of its body to bits in the most violent volcanic eruption known to man, the coarser particles of "ash" piled up inches deep a thousand miles from the volcano. Enough dust remained in the atmosphere to make lurid the sunsets of more than a year. Tiny bits of lava, carried by air currents far above the surface of the earth, found their way around the world. Less spectacular but more frequent are the dust storms of China that have been observed to extend over a distance of more than four hundred miles. Small earthy particles driven to sea during such a storm once fell on the deck of a ship at least a thousand miles from the place where they were lifted off the ground. Dust blown from the Sahara has been found in England two thousand miles away; Australian dust has

reached New Zealand; and several times volcanic dust from Iceland has fallen in Scandinavia, Great Britain, and Holland.

Rain carrying a reddish dust sometimes falls on the lands of the Mediterranean. Since these "blood rains" were first recorded in the Iliad, a great many have been witnessed over a region of considerably more than a million square miles. Not less unique than the color is the fact that the dust of these showers contains great quantities of microscopic plants and animals. Over three hundred species have been described. For a single shower that fell in the vicinity of Lyons, France, in 1846, Ehrenberg estimated 720,000 pounds of dust, of which ninety thousand pounds consisted of the skeletons of these diminutive organisms. How many tons of them have reached Europe since Homer's time and whence they came are questions that can never be answered.

Occasionally materials coarser than dust are carried high in the bosom of the wind. More than one rain of pebbles has been reported. Downpours of small live fish scooped by the wind from the surface of the sea have been alleged in India, Malay, Florida, and South Carolina. Among the less usual passengers of the wind was the turtle who arrived, so it was said, via the air on May 11, 1894, at Vicksburg, Mississippi.

There is no way of measuring exactly the vast tonnage of triturated rock moved by the wind. In the arid plateau lands of western North America the surface of the ground over extensive areas has been broken down by the various atmospheric agencies of destruction and swept clean by the restless air. Winds working through countless ages in such places have so reduced the desert floor that today it stands much lower than formerly. The more resistant mesas and buttes, defiant of destruction, rise above the general level of the land, their tops the only vestiges of the terrane that once existed. Thus it is that bit by bit and year by year the never tiring air works its mighty change.

Some of the materials moved by the wind are too heavy to be carried far. In most cases the coarser fragments of sand and rock lie quietly enough until other instruments of destruction reduce them to smaller size. Fine sand may be heaped in dunes that slowly move hither and yon at the whim of the winds. Their capricious travels bring death to vegetation and ruin to any human habitation that may lie in their paths.

All air-borne detritus, even the fairy dust, must sometime somewhere return to the earth whence first it came. Extensive deposits of volcanic "ash", dropped from the fickle fingers of the wind, occur

in many places far from the volcanoes that gave them birth. In Europe, the United States, and especially China, wind-blown particles of rock that are larger than clay but smaller than sand have been heaped many feet high over hundreds of thousands of square miles. Accumulations of this sort are known as loess. The Yellow River and the sea into which it flows receive their characteristic color from the loess; from the loess the country drained receives its fertility. Millions of Chinese live on the floors of valleys carved by rivers in earth that was blown bit by bit from the Gobi Desert. Like gophers they find it more suitable to dig holes in the ground than to build houses on its surface. Cartwheels grinding for centuries over the loess have locally returned some of it to the winds until today not a few of the roadways have come to resemble miniature canyons.

Despite the extensive deposits of windblown rock in many lands, it is not unlikely that most of the aerial freightage falls ultimately into the sea. The ocean basins usurp about three-fourths of the surface of the earth; something like a proportionate amount of the eolian cargo may well find under the waters of the sea its place of final rest. How much the winds have stolen from the lands to pay the oceans no one can precisely know. The amount may have been sufficiently large to enable the sea floors

to grow significantly at the expense of the continents.

Prodigious as is the work of carrying small pieces of rock from place to place, it is but one phase of the wind's activity. Merely transporting materials that have been loosened and comminuted by other forces does not exhaust the lusty power of moving air; enough remains to enable the winds to cut as well as carry. Clean air blowing through a passageway in a tower of the Heidelberg Schloss has worn hollows in the massive sandstone walls. Winds armed with bits of dust and sand are viciously abrasive. Even in temperate climates of abundant rainfall, where much of the loose material of the mantle is securely locked by vegetaton, the wind has been known to pick up dust from city streets and to hurl it against objects until their surfaces were worn away. Inscriptions on tombstones in old cemeteries have thus been completely effaced.

In desert regions, sand furiously driven close to the ground may gnaw like a beaver through the wood of fences and telegraph poles. Eleven years after their installation the very wires of the telegraph system of the Trans-Caspian Railway were worn by natural sand blasting to one-half their original diameter. The window panes of desert houses soon lose their transparency under the tattoo of the sand. And every desert contains formations that have been

pitted, frosted, and polished by wind-driven particles of rock. Picturesquely fretted are many formations that have resisted unequally the aerial barrage. Western United States is full of rock pedestals, "hoodoos", and other quaint formations sculptured by the eery artists of the air. Like the flesh of man which holds so briefly its form and personality, the figures of the desert are transitory shapes made only to be destroyed.

IV

Like a god in his heaven, one power more powerful than any other presides over the fate of earth and man. It engenders forces that shape the lands and determine the quantity, quality, and fertility of the soils. It orders the lives of plants and animals. It controls the migrations, the health and energy, the work and play, the very food and clothing of human beings. From pole to equator, from the mountains to the sea, the inanimate and the animate alike must abide by the decrees of this god whose name is climate.

The diversities and complexities of climate are rooted largely in two constant and simple attributes of the globe; that it is a rapidly spinning ball with an envelope of air, and that it goes its journey

around the sun with axis inclined to the plane of the orbit. These peculiarities, together with the distribution of land and water and the relief of the continents, underlie all the significant variations in temperature, wind, and rainfall the world and the year around. It is these that render vast regions too warm and moist, others too dry, still others too cold for the highest human attainment. It is very largely these that have enabled men in a few favored places to resemble more closely the angels than the apes.

In the equatorial lowlands of Africa, India, Australia, the East Indies, and the Amazon basin, a sun that knows no mercy heats the air. Day by day and year by year in nearly perfect monotony the aerial currents rise and cool and drop their moisture. The result is the heaviest rainfall and the densest forests on earth. So numerous and leafy are the trees in many places that their tops weave a canopy to retain forever the gloom of night. Vivid parasitic plants suck at the trunks of the trees, and vines hang like snakes from the branches. Seeds fall like rain from the prodigal womb of the wilderness. Of the young shoots that struggle to grow in the dank and dark of the forest floor, a few succeed while myriads die.

Some two million square miles of these rain drenched hells are so pestilential that human life is

all but impossible. Another eight million harbor a few unhappy inhabitants. Listless and naked they loll in their huts, or wearily hunt for game with poisoned arrows. If they try to make a garden, weeds and dampness choke it. If they acquire domesticated animals, the flies and an absence of tender grasses kill them. Ants and fleas and rats bedevil them; deadlier beasts and insects slay them. Swamps and thickets hold them to lonely isolation. The white men who drive them with ruthless cupidity to search for rubber, quinine, and mahogany, have made them slaves and drunkards. Beneath the soul-smothering silence of the forest they live without government, religion, or health, clinging—one wonders why—to the earth that has betrayed them.

North and south of the equator, in latitudes that approximate seven to fifteen degrees, rainfall is somewhat less persistent and abundant, and the negligible dry period of the rain-forests becomes a recognizable season. Trees are less numerous and smaller, bushes crowd the drier stretches. In places the bamboos, tree ferns, and canes, form so dense a tangle that trails must be hewn like tunnels through the brake. Monkeys and parrots make chatter in the branches, and hungry cats skulk silently below. In this, the typical jungle, men have learned to live with ease if not with richness.

Intense heat throughout the year slows down the pulse of human energy. Over great areas of jungle, few men are afflicted with the vice of overwork. They do only the little that nature demands. They build shelters of palm leaves against the rain, and forego the luxury of clothing. They plant a few cocoanut, banana, pawpaw, breadfruit, or other tropical food trees, then wait for the fruit to fall into their laps. In the more favored spots where population is fairly dense, clearings are made by burning off the brush during the dry season. The ground is punctured with pointed sticks and the seeds of corn, beans, yams, casava and manioc roots are sown. Thereafter the garden neither needs nor receives much further attention until the harvest. Because of the rapid breeding of bacteria in the soil, and the leaching of plant food by the heavy downpours, fresh patches must be cleared every two or three years.

In clearings of the tropical jungle some two or three hundred million people pursue their earthly happiness, and catch such glimpses of heaven as the rain permits. They are held to a low level of existence by the very luxuriance of their surroundings, by the superabundance of every thing but energy. Too much sun and rain and vegetation suffocates them. No ingenuity has yet availed to

enrich their lives, because they are slaves of a master who does not recognize the powers of the human mind.

Where in certain limited localities, however, the jungle has relaxed its clutch, the roots of civilization have somehow managed to bring forth their delicate bloom. Culture increases as rain decreases, matted trees give way to corn and rice. The rice fields of tropical and subtropical lands feed seven hundred million people, a civilization more numerous and uniform if not more laden with spiritual fruit than any other in the world.

The discovery of rice as a food plant of marvelous potentiality is hidden in the mists of the Neolithic Age. Although wild rice is not a conspicuous feature on the bosky face of the jungle, long before the birth of Christ its culture spread slowly eastward from India along the southern borders of Asia, and onto the islands beyond the coast. Today it continues to spread, and with it the peculiar civilization it fosters.

The island of Java, smaller than the state of Iowa, is a perfect example of the effects of rice culture in a tropical land. More than thirty-five million people—nearly the population of France—live there, and most of them raise their own food. Although half the island is a hostile waste of steam-

ing mountains, much of the remaindér is sown to rice. So nourishing is this cereal and so productive are the fields of its cultivation that a single square mile can support a thousand people. The average yield per acre is close to a ton, which is several times the food supplied by the best wheat lands in the United States.

Like all other human conditions, the rice-born prosperity of Java is a child of the earth with the stamp of its parentage upon it. Because temperature averages close to 80°F. for the entire year, because both rain and sunshine are bounteous, two or three annual crops are certain. The rolling plains at the feet of the ranges are easily terraced and flooded for the water-loving grain. Soil is kept rich and deep by the mountains, which supply not only an abundance of water, but fertilizing silt and frequent showers of volcanic dust. Nature, by a rare lapse from her normal tropical mood, has made of Java a jungle paradise.

By doing so she has made the Javanese farmers, and others like them in India and China, the most industrious, intelligent, and reliable inhabitants of the equatorial world. She has favored their lands as she has favored few others beneath the sun, allowing an unparalleled plenty to men with the proper qualities, and eliminating by slow but ruthless selection those who lack these qualities. Although the

civilization built on rice is not the highest on earth, it is a remarkable product of a region where life and death make maudlin riot, and where the dreaming of men must so generally evaporate with the jungle mist.

The culture of rice is a true child of the jungle, but many other forms of tropical agriculture are offspring of energy bred in fairer climes. Coffee, tea, cocoa, sugar, bananas, rubber, hemp, and many other products of equatorial lands have long since ceased to be luxuries in the white man's life. And long since have they ceased to be gathered haphazardly from their wilderness homes. Plantations where white men nurse them for the market dot the tropics in a belt that girdles the earth, and each year the dots increase in size and number. Beyond, however, lies the untamed jungle. Men have won their little victories only along the frontiers. Within, the domain of sizzling heat and rain is as poisonous as ever, an unanswered challenge to the human race.

V

Poleward of the equatorial belt of rising air and torrential rain, in latitudes that approximate ten to twenty-five degrees, the jungle gives way to scrub and grassland. Because the axis of the earth is tilted,

the vertical rays of the sun endlessly migrate back and forth between latitudes $23\frac{1}{2}°$ North and South. In January the sun and the belt of heavy rain shift south of the equator; in July they shift to the north. Trade winds generated by air blowing equatorwards bring seasons of dryness which alternate with the seasons of rain, and which increase in length with the distance from the equator.

In the grassy savannas of Africa and India, agriculture languishes because the sod is too tough for plowing, and because water is scarce during the period of dryness. Although the grass is coarse and not very nutritious, the inhabitants are herdsmen who drive their cattle from place to place in ceaseless search for better pastures. They never stop long enough to grow civilized. With them roam the greatest herds of game on earth: elephants, antelopes, giraffes, and many other plant-eating animals. Devoted followers—the lions, tigers and other carnivores—are never far behind.

Clearly the earth was constructed with no special concern for the two-legged mammals who dream of power. Northward of the equatorial domain lies the desert, which rivals the jungle in its hostility toward men. Much of the region between twenty and thirty degrees is in a belt of calm between the eastward blowing trade winds of the lower latitudes

and the westerly winds of the higher. The Sahara, the Arabian, the Kalahari, and many other of the world's hottest and driest deserts lie in this zone.

Gaunt and bare and forsaken, these melancholy areas are harassed forever by the furies of sun and air. Their peaks are bleak and blistered by the heat and the cold, and gashed by the occasional cloudburst. Into their desolate valleys is dumped the wastage from the ranges: the aprons of boulders at the feet of the mountain, the swirling sand beyond. Howling its maledictions, the wind lays yet another curse on the accursed land.

The plants of the desert are lean and harsh like the land they inhabit, and sparse like its blessings. And so are the animals that live on the plants and the men who live on the animals. The Arab with his pitiful flock of camels, goats, donkeys, and sheep, is doomed to perpetual wandering. He must follow forever in the wake of the infrequent shower and the grass that is born of the shower. When the reluctant skies too long withhold their limited largess, the udders of the animals fail and the young ones die. Plunder or perish rapidly become the sole alternatives. Because he is in love with life despite its bitterness the Arab easily chooses. Leading fresh horses over a hundred miles of sand and heat and weariness, he swoops like a hawk in the night upon

the camels of his victim. Reckless, fearless, lawless, proud, and poor, he is exactly what his land has made him.

The condition of desert peoples, unlike that of dwellers in the equatorial lands, improves in proportion to the rainfall. The Kalahari Desert in southwestern Africa offers a fine example of the intimate relationship of civilization and climate. In the sand of half choked stream beds and on the slopes of wind-torn mountains the naked Bushmen hunt their food with poisoned arrows. They smear their bodies with an ointment which cakes into a coat of armor against the sting of insects and the scratch of brush, and which is never endangered by bathing. They live in holes under a matting of reeds and esteem raw lice a special delicacy. Clever, cruel, and brave, they fight with the weapons and the manners of the Stone Age, utterly impervious to the civilizing influences that press at the borders of their dour land.

In less arid parts of the same desert live the Ba-Kalahari, a cattle-herding and agricultural people who seem to have been driven into the wastelands by their enemies. Forced by the country to become hunters, they cling wherever possible to their ancestral occupations. Wherever water is sufficiently abundant, they manage to acquire a small herd of goats and even a melon patch. Sober and peaceful,

they are a notch closer to civilization than the Bushmen, just as they are a step nearer the edge of the desert.

Along the grassy borders of the waste live the Hottentots with their herds. They are more elaborately housed and dressed than their neighbors of the interior, their utensils and weapons are more numerous and effective, their government and moral code unquestionably superior. They are clearly the better product of a better land. Ever with their flocks they wander along the desert brink, like outposts at the frontier of a forbidden realm.

Far to the north are other deserts which, though obviously unlike the deserts that border the torrid zone, are also strangely similar. Above latitudes of seventy-five degrees, in such lands as Siberia and Alaska, the ground is frozen throughout the year and vegetation is all but absent. Snow and ice and hunger plot death for the hopes of men. But even in polar solitudes the hopes of men are difficult to kill. Each spring they rekindle with the sun after the dark dismay of the winter night.

Hunting and fishing are the sole occupations open to those who dwell in the polar deserts. The Eskimos of Arctic lands lead essentially the lives of the Bushmen of Africa. They hunt the seal and the walrus along the frosty shores, and suffer the cold as the

Bushmen suffer the heat. Like the Bushmen they alternately gorge themselves insensible, and starve. Both are primitive savages by decree of the lands they inhabit. And just as the edge of the sun-scorched deserts is the home of herders a little higher on the ladder of human attainment, so too is the margin of the snow-blown wastes. The Lapps of the bleak but mossy tundra of northern Scandinavia, with their reindeer and simple luxuries, are the boreal equivalent of the Hottentots. Yet the Lapps, despite their blessings, are destined to view Olympus from afar. The shadow of the forbidden kingdom hangs over them, darkening the trail to the summit of their hearts' desire.

Fortunately for civilization, the forests, jungles, and deserts of the world, in all their vastness, do not usurp the entire globe. On the broad belly of the earth between latitudes twenty and forty degrees are regions of monsoon winds, which join with the trade winds to bring moist summers to the eastward margins of the lands. Along the westward margins of the same lands the summers are dry, but the winters are rainy because of the invasion of cyclical storms borne eastward by the westerly winds. In these highly contrasted climatic zones live nearly half the people of the world.

Some of the highest attainments in human his-

tory have flowered in these regions. Ancient Rome, Greece, Egypt, Carthage, Babylonia, and Syria were nurtured by the relatively dry conditions of the western subtropical zone; the hoary empires of India and China were children of the monsoon. There are good reasons for believing that the excellence of these civilizations blossomed at a time when weather conditions were more variable and consequently more stimulating than they are at present. Most of these countries today are backward, because the climate has become too monotonous to beget any special striving, because rainfall is seasonal and frequently insufficient to combat the ever present menace of starvation.

Only in middle latitudes where the west wind blows is the god of climate truly friendly to man. Widely trailing across North America, Canada, and Eurasia in the northern hemisphere, across southern Australia, New Zealand, and southern South America in the southern hemisphere, the cyclonic storms bring moderate rains and stimulating change throughout the year. These are the happy lands where the qualities that distinguish humanity in an undistinguished world have grown like plants in the sunshine.

Although these belts include only ten percent of the land area of the globe, they harbor full six hun-

dred million men. Healthier, more energetic, and more civilized than their brethren of less favored climes, these people are the lords of the living world. They control more governments, raise more food, prepare more raw materials, mine more minerals, invent and manufacture more machinery, build more railroads, bridges, and cities, sail more ships, write more books, and dream more dreams than all the rest of humanity combined.

VI

Time is a fickle lover who holds variety higher than constancy. Most regions have known marked variations in climate during their sojourn under the sun, and as a result have suffered differing manifestations of the aerial temperament. It is not necessary to turn back many pages in the history of almost any locality to find a record of days that were different.

Although most current notions of recent shifts in climate are based on tricks of memory rather than averages of the weather bureau, there is undoubted evidence in many places of certain marked climatic changes since such a comparatively recent event as the dawn of civilization. Central Asia from the Caspian Sea to Manchuria is now largely a land of

deserts. Over an area the equal of the United States, rainfall is so slight that rivers rising in the mountains are sucked dry by the parched ground and the fierce sunshine before they reach the sea. Men inhabit but a small fraction of the region, wandering in search of water and grass for their flocks, or husbanding the sparse bounty of the oases. Yet amid this desolation are the shriveled remnants of better times: of vegetation that once covered many thousands of square miles; of lakes that once were fat from generous rains, but which now are salt and shrunken under the desert sun; of caravan routes and cities that flourished only so long as there were springs to nourish them.

Then there is southern Yucatan, today a rain-soaked wilderness of tangled forests and pestilence. Its people are sickly and weak. Yet in the same area once throve the Mayan civilization, remembered in the sculpture and architecture of many a ruined city. Where the forests give way northwardly to the drier jungle, a fairly dense and progressive population still inhabits Yucatan. It has been observed in this connection that if the present line of juncture between the forest and the jungle were moved three hundred miles to the south, all the decayed cities of the Mayan heyday would lie in the drier and more healthful jungle. Huntington and other authorities

believe that some such shift must have occurred before civilization could have blossomed as it did; that the peaks of Mayan culture were reached when the climate was relatively dry. Cool healthful winters would come again to the forests of southern Yucatan if the belt of high air pressure now centered over the West Indies should move to the south. The forests would die, vigor and art might return to men.

Some such shifting of atmospheric pressure belts probably lies behind all marked changes in climate. Whatever the cause, it is certain that not only since men appeared but during the long ages that went before, the pendulum of climate has been swinging over the earth. Only the rocks and the fossil remains of plants and animals record the more ancient changes, but their testimony is striking and incontrovertible.

Thus it is that modern science can know of times when vast areas now temperate were covered with sheets of ice; when geologically not so long ago a large part of the northern hemisphere was so affected; when eons before that period glaciers spread widely over subtropical lands; when finally near the very dawn of earth history, a glacial climate lay upon southern Canada. And also in the archives of the globe is the record of days when reef-building corals lived in the water, and tropical plants on the shores

of northern Greenland. That New York was once a desert, that vegetation rich enough to make coal seams once graced the bleak surface of Spitzbergen, that the arid plateau lands of Arizona were once clothed in forests of large trees, are but a few of the facts that geologists have learned from the rocks.

Change in solar radiation, in the position of the earth's axis or the shape of her orbit, in the elevation of the continents, in the relation of land and sea, in the direction of dominant marine and aerial currents, in the amount of carbon dioxide and volcanic dust in the air, may all be partly responsible for such extreme climatic variations. No one surely knows. But whatever the ultimate causes may be, the immediate causes lie in the atmosphere itself. And thus by directing not only the alteration of rocks but also the pulsations of climate, the atmosphere, which was once thought to possess no special significance, becomes clearly one of the most important factors in the evolution of the surface of the earth and its inhabitants. Beneath an appearance of benevolent vacuity have spawned the contentions of two billion years.

III

Master Etchers of the Land

THE history of the land has been written very largely in water. Both the drama of life and of the planet it inhabits would be stilled in an instant if all water were to go out of the world. The destiny of every continent in every age has somehow been influenced by the moisture that the atmosphere has been continually filching from the surface of the earth, and continually returning.

Even over arid wastelands the heat of the sun sucks water from the rocks. Even in the frozen lands around the poles, where temperature remains for long periods below the freezing point of water, snow and ice are reduced by evaporation. Indeed, every moist surface under the sun must pay tribute to the atmosphere. The equivalent of a layer of water a yard or more deep over the entire earth is each year transformed into vapor and added to the coffers of the air. The oceans must suffer the brunt of the levy. Were not this water returned, the deepest hole in the sea would lie dry and bleached in less than four thousand years.

Anything that locally lowers the temperature of air forces its moisture to condense and in many cases to return to earth in the form of dew, frost, snow, hail, or rain. Because the atmosphere cannot retain its water vapor, its thirst is never quenched. Over the oceans where replenishment is easy, average air contains about fifteen percent less moisture than it can hold. Air over the continents averages nearer to forty percent below its full capacity. Desert air seldom rises to within sixty percent of complete saturation, and in a few places such as Death Valley, it falls short by as much as seventy-five percent.

Were the atmosphere not a Tantalus perpetually athirst, the earth might have had a vastly different history. Every waxing and waning of its waters is felt somewhere on the globe below. The gnawing and shattering of rocks when water dropped from the air finds its way into their pores and cracks is one phase of the result. The geographic diversity of climate, so dependent on the give and take of atmospheric moisture, is another. But of all phases none has been more significant for the earth herself and the creatures who dwell on her surface than the water that falls on her lands as rain and runs to her seas in rivers.

"When it rains it rains on all alike" may be a good proverb, but it is not good meteorology.

About one-fifth of the land area of the world is desert, with less than ten inches of rainfall each year. About one-twentieth is matted with jungle and soggy forest, under an average rainfall of more than seventy-five inches a year. Some thirty thousand cubic miles of rain falls annually from the clouds the world around. That which does not drop into the oceans or directly return to the air by evaporation is apportioned to the lands by the winds. So various and varying are the forces that constrain the winds, and so variable are their burdens, that the Colorado Desert may receive as little as two inches of rain in a year, whereas the hills at the head of the Bay of Bengal may gain as much as five hundred.

The traveler along the coast of southeastern Alaska worms northward among a million islands that were born when a range of mountains sank into the sea. The midsummer fog congeals to a drizzle. In the harbor of Ketchikan rain slants in unbroken lines which a puff of wind blends to a sheet. Hours he waits for sufficient abatement to permit a tour of the village. But he waits in vain and his boat shoves off into the murky sea. The skipper tells him that such a deluge is not uncommon in summer along the Inside Passage, that five inches of rain may fall in a few hours. The boat plies patiently along and more islands loom out of the mist. The near trop-

ical luxuriance of their verdure is blurred in haze, but the reason for its existence is clear.

The traveler through western North Dakota will probably see no rain, yet he will see a land where rain has sculptured strange and striking monuments. Leaving the monotony of wheat fields and barren plains he enters a region of "bad lands" similar to the "mauvaises terres à traverser" of the French. The road winds through a wilderness of grotesque shapes cut by myriad gullies in the soft shale and sandstone rocks. Stretching in all directions are range upon range of castellated buttes, temples, and domes of outlandish form and varied hue, dead cities without benefit of floral tribute.

In the layered architecture of these structures is the story of days when wandering rivers dropped their burdens on the land; when lakes were quietly choked with sediment to expire under the sun; when unnamed volcanoes gave snow-white "ashes" to the breeze. And over all is the crowning paradox of the power of water ruling its brief but violent moments in a nearly waterless land. Not in the dripping jungles of Malay nor along the rain drenched coastline of Alaska, but in the arid and semiarid wastes of the world may the traveler best comprehend its ruthless potency. There the not so gentle rain from heaven concentrates in torrents that run

amuck and destroy both themselves and the soft bare rocks which destiny denied the strength of resistance.

II

Mazourka is a canyon in the barren Inyo Range of east central California. Her enemies have made her what she is. The cloud-sucking peaks of the Sierra Nevada steal most of her share of moisture and the thirsty city of Los Angeles steals much of the rest. Wind has bruised her gaunt body until to-day she is as forlorn a piece of wasteland as ever lost the favor of God and man.

For nearly three decades Mazourka knew little of rain but the occasional showers that quickly died in the dust of her years. Then one day, as though nature had suddenly revolted against her own injustice, a black cloud piled up on the Inyo crestline to the east. It swelled until it broke, and hurled back to Mazourka in a fraction of an hour what had been denied her for a quarter of a century. But alas for such precipitate amends; Mazourka was not ready to accept them. She had no trees to retard the water as it fell, no soil to hold it to her rocky slopes. Rivers rushed through ancient racetracks of the wind.

One small tributary canyon led most of the downpour to the valley below. From its mouth the

water stormed unchecked until it reached the bib of rock débris that hangs from the neck of the range at Mazourka's lower end. A jagged gash scarred the mountainside from the place where the water had gathered. At its foot a wall of boulders rose across the canyon floor, and below, the valley was either scoured bare or filled with tumbled stone. Twenty-five minutes and the maelstrom might have been a mirage, had not that twenty-five minutes seen more history written into the unhappy annals of Mazourka than the twenty-five years that had gone before.

Geologists stress the slow but insidious working of natural forces. To witness a desert cloudburst is to be convinced of the importance of the occasional violent storm in shaping the physiognomy of earth. Mazourka's fate is not unique. It is the fate of one-fifth of the land area of the globe.

The typical desert is a basin confined more or less closely by mountain ramparts. Clouds are rare but they do at times insinuate an entrance. Hanging over the depression they grow both by evaporation from the parched land beneath them and by addition of new clouds from without. Again and again they may drop their moisture, only to have it vaporized by the heat of the desert floor, and returned. The end comes when such clouds, inordinately fattened, rise quickly on the wind against the mountain barrier.

Chilled and ruptured they give out their contents like a pricked balloon.

Ephemeral but mighty torrents swell each dusty canyon. Heavily loaded with sediment they plunge over the steep slopes, viciously scouring such rock walls as resist their wild advance. With augmenting volume and velocity they drive on to the plain below. There suddenly they encounter Nemesis. So abruptly are their gradients flattened and their velocity consequently reduced that they are constrained to drop their stony loot. Heaps of boulders, gravel, and sand grow outward from the mouths of gullies and ravines. The dying waters labor with these children of their own creation. Breaking into weakened rivulets that radiate from the mountains, each stream spreads its deposit of rock débris to the shape of a fan. The thirsty air above and the thirsty earth below unite to confer the final quietus. The rivers go as quietly out of the landscape as violently they came into it.

Apart from such great rivers as the Nile and the Colorado, which are sustained by the bounteous rains of far-off highlands so that they may defy the deserts through which they flow to suck them dry, the streams of arid lands die near the country of their birth. Despite all the wild exuberance of their mountain coursing they must abandon hope when

they enter the Inferno of the valleys below. Some of them expire quietly as described, amid wreckage of their own making. Other more lusty ones struggle on to the low places of the desert floor, only to subside in lakes whose waters are already bitter with the ghosts of aborted rivers. The Sahara, the Libyan, and the Kalahari deserts in Africa; the Taku Makan and the Gobi in Asia; much of the basin range country of southwestern United States; all, in fact, of the vast desert wildernesses of the world are graveyards for streams that jousted their brief hours with the sun, and lost.

Yet these streams that have lived so briefly have done much to mold the landscape. The intricate dissection of mountains into myriad gullies, ravines, and canyons that stand etched in the clean air like cameos, are largely their handiwork. And the mantle of loose stone draping the foot of a typical desert range is largely both produced and arranged by such streams. Sweeping in the broad and graceful undulations of fans that have coalesced at the mountain front, this drapery is perhaps the most striking element of the desert landscape. It may reach far into the middle of the basin and merge with a similar garment depending from the range on the other side. These deposits grow as the mills of time grind slowly

on. Basins wax while mountains wane, and the harsh face of the desert softens under its years.

On the crest of the Sierra Nevada the highest peak in the United States stabs the sky. Some eighty miles to the southeast, in Death Valley, lies the lowest depression. Between the two are rugged ranges of sharp relief separated from one another by trough-shaped desert valleys. Streams flowing only after the occasional storms have none the less begun to chisel into the highlands and to heap the cuttings in delta-like fans on the basin floors.

Should the country be undisturbed by convulsive earth movements for a sufficient time, the basins might be expected to be slowly filled with waste from the highlands, the heads of the fans creeping farther and farther up the canyons toward the mountain crests. Eventually the divide between two neighboring basins would be cut low enough so that the higher basin would drain across the diminished mountain barricade into the lower basin. In this fashion, eon succeeding eon, the lowest basin of the entire group would capture the drainage of all the others. Slowly interred beneath their own waste, the mountains would all but fade from view. And the wind, harbinger of a final desolation, would gnaw away the last resistant eminences, smoothing the vestiges of a noble landscape to a featureless plain.

III

The lost streams of the desert, though shaping the fate of their unhappy lands, are least significant of all rivers. Most regions are moist enough to keep their rivers permanently aflow. Their valleys are fabricated in an intricate network, endlessly murmuring with the song of running water. It is the song of destiny for most of the earth, and for most of the civilizations born to earth.

Man early found in rivers both food and drink, practical avenues of exploration and transportation as well as mystical embodiments of supernatural spirits. As rivers have run through his lands, so has veneration of rivers run through his mythology, history, and religion. He thought of life beginning between the Tigris and Euphrates, and ending beyond the Styx. The Egyptians worshipped the Nile as a benevolent goddess whose bounty sustained their civilization. Even the more practical Romans propitiated the Tiber with costly offerings. The Indians bathed in the Ganges and drank of its waters more in the interest of their souls than their bodies. The Amerindian reverenced the Mississippi as a father. The Germans enriched the poetry of the world through their emotional reactions to the Rhine. Men of every place and age have sensed the

significance of rivers in their lives, but only quite recently have any of them attempted to learn what rivers really are and what they do.

The thought of the ancients, so rich in philosophic speculations and poetic imaginings, was poor in observation and induction. Herodotus, who was born early in the fifth century before Christ, was perhaps first among the few who cared to study rivers objectively. During a visit to Egypt he was fascinated by the Nile, and later wrote critically on the various contemporary explanations of its annual inundations. Without accepting any of them or proposing an explanation of his own, he accurately apprehended the significance of these floodings. He realized that the great delta at the river's mouth was growing slowly greater. "Egypt," he said, "is the gift of the river."

A century later Aristotle had learned enough to enable him to ridicule Plato in the belief that all rivers are born in subterranean reservoirs. He observed that large rivers emptying into the Mediterranean rise in high, mountainous country. It became his belief that the mountains condensed water from the air and discharged it into channels which subsequently grew into permanent stream beds. With Herodotus he agreed that rivers build up the lands about their lower reaches. Astute observations of

this nature establish Aristotle as the leading authority on rivers in the ancient world.

Second only to Aristotle among early Greek scientists was Strabo who lived during the first century before Christ. He found time to travel widely and to write a geography of seventeen volumes on what he saw. He added much to the prevailing knowledge of rivers. Seneca, too, who lived in Rome during the first century of the Christian Era, wrote voluminously and (when he could resist moralizing) illuminatingly on rivers. The thought of these men was suggestive of the coming of a sound science of rivers, a science that unhappily was to be long delayed by indifference and error.

When, at last, curiosity about the physical world finally broke through the stagnant smugness of the Middle Ages, it did so only to run foul of the easy mistakes of the Renaissance. Until well into the nineteenth century, in fact, many an idle speculation about the earth was more generally acceptable than carefully tested truth. Thus it was that some believed river valleys the product of violent catastrophes. Others thought them the result of scouring by submarine currents at a time when a universal ocean withdrew from the continents. Still other more pious ones believed them the scars of Noah's deluge.

Such views reigned well into the middle of the nineteenth century. But sounder explanations slowly gained momentum. Before the close of the eighteenth century Steno, Guettard, and Targioni had broadly but correctly described the erosion of land by running water. It was left, however, to James Hutton to prove for all time that river valleys are the work of the rivers that flow through them. John Playfair, explaining Hutton's views in 1802, wrote:

"Every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportioned to its size, and all of them together forming a system of valleys, communicating with one another, and having such a nice adjustment of their declivities, that none of them join the principal valley, either on too high or too low a level, a circumstance which would be infinitely improbable if each of these valleys were not the work of the stream that flows in it.

"If, indeed, a river consisted of a single stream without branches, running in a straight valley, it might be supposed that some great concussion, or some powerful torrent, had opened at once the channel by which its waters are conducted to the ocean; but when the usual form of a river is considered, the trunk divided into many branches, which rise at a great distance from one another, and these again

subdivided into an infinity of smaller ramifications, it becomes strongly impressed upon the mind that all these channels have been cut by the waters themselves; that they have been slowly dug out by the washing and erosion of the land; and that it is by the repeated touches of the same instrument that this curious assemblage of lines has been engraved so deeply on the surface of the globe."

The beautiful logic of these sentences is the rock on which the modern science of rivers is built.

IV

Because the interior of the earth has been continually shrinking these many eons, her surface has repeatedly puckered and cracked like the skin of a drying apple. Such blocks and wrinkles of her crust as have raised their heads in the air have suffered the depredations of rain driven under the lash of gravity to seek the sea. Because the elevated portions of the globe have never possessed absolute uniformity of slope, the runoff to the sea has never been equally distributed in every direction. In all cases it has sought preëxistent depressions, deepening, widening, and lengthening them with time into roadways adequate to its journeying.

In imagination we can trace the fluvial history of

a virgin upland. Rain water first gathers in tiny rills and rivulets whose direction of flow is determined by original inequalities of slope. Gullies are gouged in the surface, growing deeper as more water flows through them, wider as more water enters at their sides, longer as more water runs in at their steep headward ends. Eventually they merge in continuous channels where the drainage concentrates. Not until these ravines are cut deep enough to tap the supply of underground water do they become permanent watercourses indifferent to the vagaries of the passing shower.

Once established the young stream begins vigorously to lower the slope over which it flows. Its tools and methods are manifold. Through the strength of its movement it carries off fragments of earth and rock already loosened by the disruptive activities of weathering. By dissolving the soluble minerals in the bottom and sides of its valley it gains further material through its own efforts. That portion of its load which is not carried in solution is roughly jostled downstream. Fragment bumps fragment with a slow decrease in the average size of the particles and a slow increase in their roundness as the corners are worn away. The bedrock below is scoured as the larger and heavier pieces rub over it, and the valley gnaws ever deeper into

the upland. As long as there is any considerable difference in elevation between its upper and lower ends the stream will continue to eat steadily downwards.

The landscape melts from one form to another with the advancement of streams through the cycle of their existence. For some time after the initial integration of the drainage system, the adolescent rivers expend their vigor in deepening their channels. They sink into narrow V-shaped gorges whose steep sides meet the upland in unsoftened angles. Tributaries grow rapidly like branches from the trunk of a tree, dissecting and narrowing the flat divides between adjacent streams.

In the youth of the landscape this tendency has not yet progressed to any considerable extent. Main streams are few, tributaries are but meagerly developed, divides are broad and poorly drained. In the canyons water booms over irregular, steep, and crooked channels, frenzied with the task that lies before it. Nowhere among the angles and straight lines of the scene is there a curve to rest the eye. But grandeur may take the place of grace. In the gorges of youthful rivers lies some of the sublimest scenery in the world.

West and south of the Rocky Mountains, a far-ranging plateau lifts its broad back to the sky. The

wide acres of western Colorado and New Mexico, as well as most of Utah and Arizona, comfortably straddle the colossus. Underneath are rocks of ancient lineage, offspring of forgotten seas and the dead waters of vanished lands. They record the fortunes of four geologic eras, the shifting events of more than a billion years. Yet not for this is the region remarkable, but rather for the mysterious convulsion that came with the dawn of the fifth and most recent era in its history; which elevated the plateau almost without distortion several thousand feet above the sea, and raised the curtain on the most spectacular drama of erosion the world has ever seen.

Rivers flowing over the new land stripped an untold tonnage of rock from its surface until their vigor died with the flattening of their gradients. Then, when the mighty glaciers of the last ice age began to creep out of the North some million years ago, the plateau was again uplifted and tilted southwards, this time to its present elevation of seven to eleven thousand feet above the sea. Sluggish old rivers were rejuvenated and set once more to excavating their valleys. The drainage was reorganized and the Colorado River system was born.

Fed by the rains and snows of the Rockies, the Colorado River flows two thousand miles before

joining the sea, and with its tributaries, drains nearly a quarter of a million square miles. For five hundred miles it traverses the high bleak table lands of its upper reaches in a long series of gorges carved by its wild, young, sandy waters. Much as a buzz saw in a sawmill cuts through a log, the Colorado has cut into the slowly rising plateau. The Grand Canyon, over two hundred miles long, eight to twelve miles wide, and more than a mile deep, is the greatest of the gashes and the most spectacular example of river sculpture on earth.

A wilderness of templed buttes, detached from the plateau by the river and its tributaries, rises in tiers of multi-colored rocks like mountains from the canyon floor. Their awful beauty under the shifting lights both challenges and defies description. Several have tried but none has been able to express in words or painting the inscrutable charm of this truly Grand Canyon. Men might better let it speak for itself.

And men who value their comfort and their lives had better view the spectacle from the pleasant hostelries on the rim. Only a few, it is true, have ever been tempted to explore its mysterious depths, yet of these not all returned to relate their experiences. Among the most daring ventures in the history of exploration was the expedition of

Major John Wesley Powell, one-armed veteran of the Battle of Shiloh, the first to complete a passage of all the canyons of the Colorado.

When, in 1867, Powell first conceived the idea of his dangerous project, little was definitely known about the river and its canyons. In 1540, Don Lopez de Cardenas of Coronado's expedition heard of the Grand Canyon from the Hopi Indians and was the first white man to stand on its rim. More than two centuries elapsed before the region was again seen by white men, the two Spanish priests who crossed the river in 1776. Another half century passed before the first American trappers arrived. By 1850, government exploring parties began to drift over the Colorado Plateau, but these were content to cross the river at the fords and to leave its canyons alone. Even the Indians dared not tempt their wrath. When Powell with nine men and four boats left Green River City, Wyoming, on May 24, 1869, it was generally believed that the Colorado River ran underground for several hundred miles, that certain death awaited anyone who ventured down its turbulent and mysterious course.

Although the party failed to find any subterranean passageways, they did encounter hundreds of rocky cataracts where the water churned in great waves over long stretches at the rate of twenty miles

an hour. When in August they entered the Grand Canyon itself, one of the boats had been smashed to driftwood in the rapids of Ladore, scientific instruments had been lost overboard, provisions were nearly exhausted. With starvation beckoning from the desert shore and death by drowning the sole promise of the river, Powell wrote in his diary:

"We are three quarters of a mile in the depths of the earth, and the river shrinks into insignificance as it dashes its angry waves against the walls and cliffs that rise to the world above; they are but puny ripples, and we but pigmies, running up and down the sands, or lost among the boulders.

"We have an unknown distance yet to run; an unknown river yet to explore. What falls there are, we know not; what rocks beset the channel, we know not; what walls rise over the river, we know not. Ah, well! we may conjecture many things. The men talk as cheerfully as ever; jests are bandied about freely this morning; but to me the cheer is somber and the jests are ghastly!"

Four days later this entry was made: "The stream is still wild and rapid, and rolls through a narrow channel. We make but slow progress, often landing against a wall, and climbing around some point, where we can see the river below. Although very anxious to advance, we are determined

to run with great caution, lest, by another accident, we lose all our supplies. . . .

"We make ten miles and a half, and camp among the rocks, on the right. We have had rain, from time to time, all day, and have been thoroughly drenched and chilled; but between showers the sun shines with great power, and the mercury in our thermometers stands at 115°, so that we have rapid changes from great extremes, which are very disagreeable. It is especially cold in the rain tonight. The little canvas we have is rotten and useless; the rubber ponchos, with which we started from Green River City, have all been lost; more than half the party is without hats, and not one of us has an entire suit of clothes, and we have not a blanket apiece. So we gather drift wood, and build a fire; but after supper the rain, coming down in torrents, extinguishes it, and we sit up all night, on the rocks, shivering, and are more exhausted by the night's discomfort than by the day's toil."

Near the lower end of the Grand Canyon the boats plunged into Granite Gorge, the worst stretch of the entire river. Somehow its cruel rapids were negotiated without mishap, but when another granite gorge appeared the courage of the men was shaken. Three decided to desert and broached their project to Hawkins, the cook, who stoutly refused to join

them. Writing of the episode later, Hawkins said, "While we were talking, the major came up to me and laid his left arm across my neck, tears running down his cheeks. By that time the rest of the boys were present, and the major said to me: 'Bill, do you really mean what you say?' I told him that I did, and he said that if he had one man that would stay with him he would not abandon the river. I just simply said that he did not know his party."

But the three deserters persisted in their plan, and climbed out of the canyon in search of a Mormon settlement somewhere to the north. Powell and "the faithful five" pressed on. Next day the boats suddenly emerged from the rapids and quicksands of the canyon and entered the calmer water below. In a week they reached the Rio Virgen and friends. Powell, relaxed at last, wrote in his diary:

"Ever before us has been an unknown danger, heavier than immediate peril. Every waking hour in the Grand Cañon has been one of toil. We have watched with deep solicitude the steady disappearance of our scant supply of rations, and from time to time have seen the river snatch a portion of the little left, while we were ahungered. And danger and toil were endured in those gloomy depths, where oft-times the clouds hid the sky by day, and but a narrow zone of stars could be seen at night. Only

during the few hours of deep sleep, consequent on hard labor, has the roar of the waters been hushed. Now the danger is over; now the toil is bounded only by the horizon; and what a vast expanse of constellations can be seen!

"The river rolls by us in silent majesty; the quiet of the camp is sweet; our joy is almost ecstasy."

The deserters, on the other hand, fared less well. On the plateau above the canyon they encountered the Shewits Indians, who administered the fate they were so desperately trying to escape.

V

Continued growth of rivers like the Colorado reduces the flat-topped divides both between tributaries and neighboring streams to rounded ridges. In regions of sufficient moisture the main streams multiply and weave an intricate network of branches over the land. The original upland fades into a sea of hills and valleys, its straight lines and harsh angles everywhere molded to curves under the inexorable attrition of the weather.

In this, the maturity of a river-carved land, every raindrop finds a ready-made channel that will lead it ultimately to the sea. On the perfectly drained

divides no water idles in lakes and swamps. Because of the bounteous increase in the number of side streams, many fresh slopes suffer the attack of weather and add to the burden of the water. Main streams have so lowered their gradients and smoothed the irregularities of their beds that waterfalls and rapids exist only in their extreme upper reaches. Lower down they wander from side to side, sometimes with enough force to cut into the retaining walls and widen their valleys, sometimes flooding and dropping layers of mud and sand upon their enlarged valley floors. Halfway between the cradle and the grave they meet, like men, their heaviest tasks, and win, if it is so ordained, their greatest victories.

Although the collective goal of rivers draining a mature region is to reduce the country to flatness, the individual aim of each stream is to increase at whatever cost its own domain. Struggle for existence is fierce, and if any stream is favored over a neighbor by flowing through softer rocks or down a steeper slope, it may eat through the intervening divide and steal the headwaters of the less fortunate one.

The various methods whereby streams adjust themselves to the conditions imposed by the varying nature of the lands they drain give them a fascinat-

ing diversity of character. In western West Virginia, for example, the rocks are nearly horizontal and the rivers in their maturity have spread with even tree-like growth in all directions. To the east, on the other hand, the rocks are strongly flexed in wrinkles from the northeast to the southwest. Long straight streams have cut channels in the weak rocks between the wrinkles, their trellis-like tributaries stretching but short distances up the resistant ridges on either side.

In the end, however, if earth movements do not disturb the orderly progression of the cycle to its normal finish, streams vanquish all opposition. Divides are worn down until only the most stubborn masses of rock raise their hulks above the monotonous expanse of the aged landscape. Competition has reduced the number of main streams, and the survivors flow wearily to the sea. Their shallow valleys are lowered throughout nearly to the level of their mouths, the level below which they can no further degrade their channels. Listlessly they wander in broad meanders, flooding out of their beds when the freshets and melted snows of spring fall upon them, and dropping great quantities of mud and sand over wide belts of lowlands. Between them the country is flat as in youth, with swamps and lakes souring in the sun.

Because at present the continents stand higher above the sea than they have stood during most of the past, such old age surfaces as exist in the world today no longer lie near the level of the mouths of the rivers that produced them. Raised and tilted by subterranean unrest, they are undergoing a re-enactment of their past history. A new generation of rivers has been born to them, new young valleys are trenching their flat expanses. But the new cycle has not entirely obliterated the imprint of the old. In more than one locality the broad divides between youthful streams are clearly remnants of an ancient surface of river degradation.

Nature is full of reverses. Underworld forces may interrupt at any stage the orderly development of a river-carved terrane. Elevation of the land may renew the waning vigor of the streams and throw the region back to an earlier condition in the normal sequence of its evolution. Sinking of the land, on the other hand, may emasculate the streams by flattening the slopes over which they flow, thus ending the cycle of erosion without inaugurating a new one. It may even depress the mouths of the rivers below the sea, drowning their lower reaches and changing them into estuaries such as Chesapeake Bay. Desert climate may fall upon a humid region, killing the permanent streams and ending the cycle of their

development. Glaciers and lava flows may overwhelm them so that they must start anew. Yet despite vicissitudes, the rivers of moist countries have endeavored to develop according to the plan described. Each stage in the life history of the stream-sculptured landscape may be seen somewhere on the surface of the earth today.

VI

All rivers are essentially ungovernable, but the older ones have been the chief transgressors against the human will. The history of the lower Mississippi Valley has in no small measure been the history of the attempt to control the fretful stream that drains it, and whose whim it is to bestow both fortune and disaster without discrimination.

From Cairo, Illinois to the Gulf of Mexico, the Mississippi labors over land of its own making, over layers of mud and sand laid down since the day when it entered the ocean more than a thousand miles above its present mouth. Staggering in wide curves over its broad valley, it drops much of its vast burden short of the goal. But the water presses on, breaking finally into radiating distributaries that cut new channels through the self-imposed barriers, as it fights its way to the sea. What sediment is left

in the frayed ends of the river is dumped when the currents lose themselves in the ocean. Thus has grown the delta of the Mississippi through the centuries. The banks of the major distributaries are still growing at the rate of a mile in sixteen years, paying to Louisiana what was stolen from her northern sisters.

The river, however, exacts a goodly toll for such beneficence. So gentle is its gradient for hundreds of miles above its mouth and so easily are its waters deflected that no property within the scope of its shifting whims is ever secure. It may wear such deep curves in its channel that a boat might travel as much as thirty miles downstream only to arrive in the end within a mile of the starting point. In flood the river may cut through the narrow neck of land between the ends of such a horseshoe meander, straightening its channel and converting the old bend into a crescent-shaped lake. Plantations once so profitably situated within the margins of the loop find themselves far from the river that must convey their produce to the market.

Inconvenience thus results from the continual shifting of rivers. Disaster falls when a swollen stream rises out of its channel and floods the broad lowlands on either side. The government of the United States has already spent some two hundred

million dollars in a valiant attempt to hold the lower Mississippi to an ordered course, a fact which, alas, the lower Mississippi disdains when under the spell of an expansive mood.

In earlier days before the ax had come to the forests of the Appalachians and the plow to the western plains, rain and snow falling on the far-flung drainage basins of the upper Mississippi were retarded by vegetation in their vernal rush to the sea. Civilization and deforestation advanced together, with disaster trailing in their wake. Unable to hold the augmented waters to normal channels, the weak mud banks of the lower river yielded to repeated overflowing. The surging tide of flood spread far and wide and often, sowing ruin over the land.

With each rising out of its channel the velocity of a river is suddenly checked, so that mud and sand settle in successive layers over the flooded areas. At the margins of the channel, where the first slackening is felt, the alluvium forms embankments that grow with repeated floodings above the general level of the valley. As these natural levees grow higher they combat the overflowing that brought them into existence. Taking his cue from nature, man has reenforced the levees in an attempt to keep the river off his lands.

More than fifteen hundred miles of levees have

been raised as much as three feet above the highest recorded flood on the lower Mississippi. By this means many a disaster has been averted and many an acre of swamp land reclaimed for agriculture. But in low water the stream aggrades its channel between the embankments so that it is necessary to build the levees ever and ever higher. Along the lower reaches of more than one large river the water is actually flowing at higher levels than the house-tops on the valley floors. When the levees of such rivers give way, disaster is more deadly than in regions where no levees exist.

The day has not yet arrived when the states of the lower Mississippi Valley may feel sure of the dikes that guard the lives and property of so many of their people. The river is treacherous and at any time may begin to undercut its barriers at unexpected points. Mattresses of willow trees joined by steel cables have been placed along the curves where erosion is most menacing, but there are yet many stretches of potential danger where no such revetments have been erected. Reservoirs to impound flood water before it reaches the lower valley are being constructed, and reforestation is slowly advancing against private greed and public indifference. Perhaps it is not an utterly forlorn hope that some day this giant may be chained.

Should that ever come to pass, human intelligence and will would gain a significant victory. Long before man appeared on earth, rivers were the lords of her lands, the master administrators of her fate. Should man succeed in taming even one great river, his favorite belief in his own omnipotence would be rendered less a delusion.

VII

Yet rivers, like most other natural forces, need not be subdued to be useful. They are in their nature both a blessing and a curse upon mankind. So many and great have been the benefits derived from running water that an occasional disastrous flood seems no very exorbitant price to pay for them. No other force, indeed, has more effectively directed the journey from savagery to civilization. Rivers and the history of man have flowed together.

Primitive peoples gathered as naturally to the flood plains of rivers as flies to meat. On the lush alluvial meadows the nomad must early have found abundant food for himself and his flock. He lingered to dabble in agriculture with such happy results that he dreamed no more of distant pastures. His descendants are still there. Most of the people of the earth are there. The basin of the Ganges

alone supports more human beings than does the continent of North America.

Throughout the ages, human ingenuity has groped for comfortable adjustments to the whims of the water. Periodic floodings nourish the fertility of the fields but endanger the homes and the lives of the tillers. Although adaptations to this fundamental dilemma have been many and varied, they have achieved improvement but not perfection. The mound villages of the White Nile are anachronisms in the modern world. When freshets change the flood plain of the river into a marsh, the giant hillocks of the white ant and the refuge huts which the natives have built on them project above the water. Elsewhere in Africa and in China, river people have erected artificial mounds for a similar use, after a fashion that was probably universal in the past.

With the advance of time and the growth of civilization such meager defense against flood was replaced by more elaborate systems of dikes, dams, and ditches. Men everywhere united in common effort to check and distribute the waters that ramped through their homelands. Their success has been far from complete because their foe is essentially unconquerable. Their most significant victories have been won not over the rivers but over themselves. Banded against a common danger, laboring towards a com-

mon good, men learned as they could have learned in no other way the art of coöperation. In Egypt, China, Mesopotamia, India, Persia, Peru, Mexico, and New Mexico, civilization grew in the valleys of rivers with the growth of flood control and irrigation.

The story of Egypt well shows how a river may break down the sterile individualism of those who come to dwell on its banks. While Europeans were still throwing stones at animals, the Egyptians were being fattened by the Nile into a great nation. Barbarous men of diverse origin—children mostly of Ham and Shem—flocked from every direction to the fertile alluvial plains. Gradually under the subtle persuasion of the river, their ethnic differences were washed away. They united in one government with the one purpose of husbanding the bounty of the Nile. And they were abundantly successful. Under the Pharaohs they stretched the fingers of their control from the delta to the far Third Cataract. They rose from barbarism to wealth, leisure, and culture. Their accomplishments in art, science, government, and engineering have been woven into the fabric of every subsequent civilization.

The valleys of streams are highways as well as homes, and through them the argosies of exploration have ceaselessly coursed. The rapid and suc-

cessful colonization of new lands has depended very largely upon the navigability of their waterways. The invasion of North America by Europeans advanced along the rivers, particularly the St. Lawrence and the Mississippi. South America, gashed to the backbone by deep wide streams, became considerably less of a geographic enigma within a few decades of its discovery. Africa, on the other hand, long remained essentially unknown because the seething cascades in its rivers barred the explorer's path.

Commerce follows in the wake of exploration. In North America the fur trade expanded through the St. Lawrence and the Great Lakes to the waterways of the Mississippi, in a vast network of trade that reached to Edmonton on the upper Saskatchewan and to New Orleans on the Gulf of Mexico. Similarly the Russian hunters trailed by water to the Pacific. The north-south highway of the Rhine and Rhone, and the east-west avenue of the Danube have always been the most vital trade routes of Western and Central Europe. Commerce has ridden these rivers since Neolithic days, and with commerce, culture and war.

The life blood of China flows with the waters of the Yangtse River. Ocean steamers safely ride its gentle currents to Hankow, seven hundred miles above the mouth. Smaller steamers advance an-

other three hundred miles to Ichang, and even beyond the rapids far into the hinterland. The fertile farmlands of the interior and the bustling cities of the coast are thus united. For two thousand miles the Yangtse is the most powerful bond in the union of a far-flung realm, the most effective artery in the nourishment of a population that outnumbers the inhabitants of the entire western world.

Thus endlessly examples may be multiplied. With the latter day creation of more rapid modes of transportation and communication, rivers are still woven into the stuff of human life. The gods who set the terrestrial scene decreed that streams and men shall ever be at one. Even in the rhythms of their evolution they are at one. Rivers are born to die and to be born again, just as are the civilizations that spawn in their valleys.

The ancient civilizations of Egypt, Babylonia, and China were born in the common effort of men to exploit the resources of rivers. They matured to greatness with the success of the effort. Then Egypt and Babylonia, softened by wealth and leisure, fell prey to covetous neighbors. China, better protected, fell asleep. All declined because the gods decreed that success and failure shall rotate in this whirling world.

IV

Waters That Work in the Dark

THE forthright forces of running water that wreak their havoc at the surface of the earth are ably abetted by other more insidious forces that work like worms beneath the skin. Invisible throughout most of their range, the hidden waters that seep through the pores and crevices of rocks are yet significant in the attempt of erosion to level the lands. Silently they have marched these many eons in the atmospheric army of destruction. The victories they have won are unique, deserving of more than passing mention in any undistorted chronicle of terrestrial conflict.

The disclosure of flaws in unsuspected places is a major phase of life's disenchantment. Even the concept of *terra firma* must be qualified to the verge of denial. Rocks are not nearly so defiant of destruction as they may seem to the casual eye. Their days, like our own, are numbered.

Close scrutiny reveals weaknesses in even the strongest of them. When igneous rocks contract from liquid to solid they invariably split into blocks

of various sizes and shapes. Sedimentary rocks are not only divided into the layers that mark changes in the conditions under which they were deposited, but they are cut by shrinkage and compression cracks as well. Metamorphic rocks exhibit fractures inherited from their igneous and sedimentary parents, in addition to others engendered by heat and pressure. And rocks of every descent, even the most tightly knit, are porous. The percentage of pore space varies with the nature of the rock, from less than one to as much as forty percent.

Experiments with rocks under pressure have led to the belief that cracks and pores may occur only in the uppermost layers of the earth rind. At eleven miles below the surface the weight of overlying formations must be sufficient to render even the sturdiest rocks plastic, and to squeeze all their openings out of existence. Weak rocks are doubtless sealed at shallower horizons. Percolating waters are thereby held within a relatively superficial zone, their cankerous touch securely barred from the inner depths.

Of all subterranean waters that once knew the light of day the deepest and most stagnant are the saline relicts of ancient seas. With the shifting fortunes of the globe these waters were buried under the sedimentary accumulations of the continents. Hermetically closed against evaporation and restrained

from free circulation, they are bitter remembrancers of a destroyed landscape and a forgotten age. A whim of destiny preserved them through all the vicissitudes of time for no apparent reason. Unless tapped by deep mine shafts or oil wells, they lie quietly in their beds, unmoved by the conflicts raging about them.

In contrast with the senile apathy of these imprisoned brines is the juvenile energy of the waters that have escaped the volcanic chambers of their birth to rise through fissures toward the surface. Water is a common constituent of the vapors released from the lavas of active volcanoes; it must also exist in the subterranean mixtures of liquid rock that never quite win an outlet. Many geologists believe that certain springs in regions of expiring volcanic activity are liberating water that was never before at the surface of the earth. Such are the sodium carbonate waters of Germany, France, California, and several other areas; such too are the sodium chloride-silica waters that spout from the geysers of Yellowstone Park, Iceland, and New Zealand.

Virgin emanations of this sort only too soon lose their virginity by mingling with waters that have seeped into the ground from above. It is consequently difficult to identify them with certainty, and to know how abundant they are in the vast and varied

troop of waters that search the rocks. The most trusted criterion for their recognition in springs is the comparative constancy of their chemical composition, concentration, and rate of flow. Underground waters of atmospheric origin are far less consistent in these regards.

However abundant they may locally be, both the entrapped remnants of vanished seas and the hot aqueous oozes from pockets of liquid rock are distinctly minor brigades in the army of underground erosion. The waters that lie in the bottom of wells, that trickle through the shafts of mines and over the walls of caverns, that work endlessly and significantly toward the alteration of the lands, are very largely rain seepage from above. Slowly insinuating themselves through the pores and fractures of the crust, these waters have spread into thin shallow oceans beneath the surface of every land mass on the globe. Drought may shrivel the farmer's crop, but the well that saves the farmer will probably in its turn be saved. The rains of many and far off places are its food; if one source of supply is closed, others remain open. There is scarcely a patch of desert on earth that is not generously watered underneath.

Where rain falls bounteously but not too fast, where slopes are wooded and not too steep, water soaks into the gound under the persuasion of gravity.

It filters through the unconsolidated grains of soil into the rocks below. Cracks and fissures provide easy channels to greater depths, but the chief avenues of descent are the interstices between the particles that constitute the rock formations. If the pores are relatively large and abundant, as in coarse-grained sandstones, the water moves slowly but surely through them. If the pores are relatively small and few, as in granite, the flow is retarded to within the shadow of stagnation. If the pores are abundant but very minute, as in clay and shale, each drop of water is held like a prisoner in a cell by the molecular attraction of the tiny fragments of rock. It is scarcely more able to move than is a bit of iron in the grasp of a magnet.

At depths that vary from place to place with the nature of the rocks, and which fluctuate with the amount of rainfall, underlying formations are saturated with water. The top of this zone is the "water table" sought by wells. It limns a faint replica of the land surface above, rising beneath the hills, falling beneath the valleys, but sometimes cutting the lower valley walls to issue as springs and to mingle with the water of streams, lakes, and swamps. In moist climates the water table lies within two or three hundred feet of the surface; in deserts it may sink to more than half a mile below. The bottom

of the saturated zone is not far beneath the top, for nowhere is the underground sea more than a meager film in comparison with the radius of the earth. The deeper shafts of many mines cut through the water-logged zone into rocks that are dry and dusty.

In its war with friction, the force of gravity normally wins the slight victory of imparting a sluggish flow to the water in the saturated zone. Under exceptionally favorable conditions in an Arizona mine, ground water was found to be moving at the rate of nearly a mile in a year. The average rate is doubtless slower, perhaps but a few hundred feet in a year. But despite its sluggish disposition, its limited distribution, and its tenuous constitution, the waters of the nether kingdom have worked sufficiently well to be ranked among the chief players in the drama of earth.

II

The shifts of a shifting world are ever along lines of least resistance. Even in the dark recesses of its domain the subterranean flow seeks channels that permit progress with a minimum of friction. Formations whose pores are relatively many and large, whose extent is considerable, and whose inclination is sufficient to induce movement, provide major runways for the hidden streaming. Forma-

tions whose pores are relatively few and small constrain the waters to the more permeable zones, holding them to their courses much in the fashion of the banks that flank the rivers of the surface.

The abode of underground water is not a Tartarus of perpetual banishment. Topographic irregularities in many places cut the water table so that the aquifers may return their travelers to the air and light. Springs gush from the hillsides and feed the rivers in the valleys below. With time the rocks are worn by the trickle, the hillsides are undermined, the springs retreat into recesses of their own creation. The little streams flowing out from these lush coves grow longer, and eventually the stronger of them may carve miniature valleys. Rivers are normally ambitious to extend their drainage basins. Not infrequently they seize upon such spring-born waterways and incorporate them as tributaries. Some of the deserters from the forces of surface erosion are thereby brought back to camp.

Steadiest and lustiest of springs are those that rise through cracks that deeply sever the water-bearing formations. A fissure may cut through an inclined series of rocks so as to meet the surface of the land well below and far away from the intake of the aquifer. Enough pressure will then exist to force the water upwards between the fissure walls whence

it may issue in a series of long-lived springs. On desert wastes such springs are the rare boon of a penurious land. Lapsing at intervals from hostility, nature yields the cool bounty of her depths. Palm trees spread their fronds over the bubbling pools and the weary traveler rests.

The fame of certain fissure springs has traveled round the world. Giant Spring on the bank of the Missouri River near Great Falls, Montana, is itself a veritable river rising from the rocks. Along the Mediterranean coast are similar gushings that spout like fountains from the ocean floor. From the bottom of the Gulf of Argos in Greece a mighty flood of fresh water wells through the surrounding brine without contamination, and bows up the surface of the sea.

Artificial fissure springs are produced when ground water under pressure is tapped by pipes. So great may be the hydrostatic head that the water flows or even spouts from the outlet. Running wells of this nature are called artesian from the French province of Artois where they were first drilled. Some of them are less than one hundred feet deep but others drain formations lying as far as a mile or more below the surface. Occasionally the water in an artesian well runs wild with eagerness to seek its level. "Jumbo" of Belle Plain, Iowa, widened a

two-inch drill hole to three feet, and boiled from the ground in a fountain five feet high. Nearly six weeks were devoted to a futile attempt to control the terrestrial hemorrhage, during which time (it was soberly sworn by local observers) "Jumbo" consumed untold tons of sand and clay, forty carloads of stone, one hundred and thirty barrels of cement, and enough lead pipe to destroy the credulity of all who were not eye witnesses.

Springs bring strange gifts from the underworld. Their waters are prowling thieves that filch all manner of mineral matter along the dark trails of their wandering. In the air evaporation, release of pressure, loss of carbon dioxide, and the presence of tiny plants that secrete mineral water, disturb the chemical balance of the solutions so that minerals are deposited as incrustations on the ground around the orifices.

These deposits are as varied as the formations through which their mothering waters have moved. In one region layers of limestone give lavishly of calcium carbonate; in another gypsum beds yield calcium sulphate; in yet another salt lenses in the rocks add sodium chloride to the hungry percolates and their surficial accumulations. Some springs are rich in silica, others in iron, still others in soda and borax; some are acid, others are alkaline; some steam with heat, others freeze the hand. In one place water as

pure as new snow gurgles from a crevice; in another the fumes of hydrogen sulphide befoul the countryside. Some spring waters are so charged with carbonic acid that they effervesce upon release from the earth. In others lurk the rare and phlegmatic argon, helium, krypton, and xenon gases. Even such metals as copper, lead, zinc, quicksilver, antimony, arsenic, gold, and silver, may reside in the bosom of ascending ground water, and may precipitate at the mouths of the conduits that lead it to the surface.

High on the flattened backbone of the continent in the northwestern corner of Wyoming, the traveler enters the weird world of the Yellowstone. Beneath his feet are upwellings of liquid rock that are dying just short of the release they seek. Hot juices escape from the stiffening magmas, mingle with the seepage of the rains, and rise through cracks to the surface. Limpid pools of green and azure quietly simmer in rainbow-tinted hollows. Strangely beautiful crystal cauldrons storm with a mysterious discontent. Vile pools of crawling mud exude the stench of sulphurous vapors, and columns of steam like ghosts in the moonlight troop to the sky.

Near the northern boundary of the Inferno is Mammoth Hot Springs whose heaps of travertine rock gleam in the sun like drifted snow. The deposits are oddly tiered, and the hot limy solutions

that still flow over parts of them give a clue to their origin. Cascading down the terraces, the water spreads to a thin veneer at the places where it begins to descend from one level to another. There it rapidly cools and drops most of its mineral freightage. Thus through time the steps of a mighty staircase have been built, with little pools of water nestling in each backward dipping tread.

Although yet active in its maturity, Mammoth has bid farewell to the vigorous days of youth. The luster of its tufa palace has waned with the waning of its waters. Similar springs in other places are working far more effectively. At the baths of San Vignone in Tuscany a six-inch layer of calcareous rock is added every year. At San Filippo, Sicily, a travertine hill some two hundred and fifty feet high and over a mile long has grown from the waters of a hot spring; and continues to grow higher at the astounding rate of three feet annually.

When hot springs are rich in silica, microscopic plants may impregnate the mineral as it gathers about the vents in gelatinous form, imparting a pink, red, or golden-yellow color. The deposits vary from a creamy white in the hotter waters to aquamarine in the cooler. But even the plants that thrive in these unholy places must sometime pay the inevitable

price of living. When they do the color fades and the silica becomes like old cheese.

Strangest in the whole strange family of thermal waters are the gushing hot springs known as geysers. They rise from deep narrow fissures where convection currents are so retarded that heat is not equally distributed through the tall column of water. Consequently the water near the bottom comes to the boiling point sooner than does that at the top. Steam forms below and forces a flow of water from the vent above. The pressure throughout the column is thereby reduced so that a large quantity of water is suddenly converted to steam. With a roar the geyser erupts.

Not all geysers are as dependable as Old Faithful in Yellowstone Park. Some play fitfully with long and irregular periods of quiescence. In New Zealand Waimangu spouts erratically from a small, innocent-appearing pond. In her heyday she could hurl a jet of mud-blackened water to a height of fifteen hundred feet. Harmless enough when quiet, Waimangu has destroyed more than one unwary visitor in her unpredictable bursts of wrath.

III

Not against man, however, do the legions of ground water wage their major wars, but against the rocks beneath his feet. Their occasional escape to the surface in springs is no significant phase of their activity. That by so doing they should sometimes kill, cure, or amuse a human being is of even less significance. Natural forces are fundamentally neither hostile nor friendly to man. They are merely indifferent.

They bestow salvation and damnation with perfect impartiality because they bestow them accidentally. In one breath a volcano buries a city, in another it fertilizes a state; and nowhere is it proved that the volcano has any interest in either result. Nor does the water that works its devious way through the rocks much care how it impinges on human concerns. It happens to be far more helpful than harmful to man, yet it sometimes strikes a deadly blow. Geysers surging blatant and heedless from the ground have taken a toll from humanity, but they are minor killers when compared with the waters that steal silently into the rocks on steep slopes and bring whole mountainsides crashing to the valleys below. Although landslides are the merest byplay in the drama of earth they may be major tragedies

for man. As such they demand at least a paragraph or two.

During severe rainstorms heaps of loose rock gather at the sides of mountain highways. They demonstrate the effect of water soaking into the pores of soil and gravel deposits that lie in steep places. Where accumulations of rock débris rest on beds of clay, lubrication by ground water renders the latter slippery and allows the former to slide downhill. Even consolidated rocks may become so weakened by the insidious advance of percolating waters that huge blocks suddenly collapse to lower levels. The traveler in the Rockies may see the ugly wounds of many landslides not yet healed by vegetation.

Landslides have written an unhappy chapter in the annals of mountain people. In 1348, thirteen Swiss villages were buried under one slide from the Villach Alp; in 1806, five hundred people in four villages were swallowed by the fall of the Rossburg. A full list of the landslides known to history would make a sadly extended catalogue of calamity. Perhaps the greatest of all was the slide that occurred on one of the far headwater streams of the Ganges. The front of a mountain in the central Himalayas became so badly honeycombed by springs that without warning one day the entire face crashed down. Eight hundred million tons of rock built a dam

across the river nearly one thousand feet high. The impounding water formed Gohna Lake, which grew four miles long in a year. Eventually the lake rose to the top of the dam and the water began to pour into the lower valley. Gaining power as it flowed, it enlarged to a terrible flood that partially destroyed the dam and drained the lake in four hours. Roaring forward it buried the valley to a depth of well over one hundred feet. When at last it subsided, not a trace of man remained in one hundred and fifty miles.

Northwest of western Montana the Front Range of the Rockies looms in a nearly continuous wall that separates the jumbled mountains of British Columbia from the prairie lands of Alberta. In only a few places have streams cut through the barricade, and these places have been major arteries of exploration and commerce. Just north of the International Boundary is Crow's Nest Pass, the most southerly and perhaps the most important pass in the Canadian Northwest. History has moved for many decades through its rock-ribbed defiles, history in whose ranks once stalked one of the grimmest tragedies of modern times.

Over the divide in Alberta lies the little town of Frank. Close by, the hulk of Turtle Mountain rises in a mass of tilted limestone beds above a base

of coal-bearing shale. On April 28, 1903, the town was not unlike many another mining community of the Far West, and Turtle Mountain was just another mountain. But the next day brought a terrible change.

Mr. McLean who kept a boarding house in Frank was an early riser. It was four o'clock and dawn was beginning to break. Ten minutes later he heard an ominous noise that brought him to the door with a rush. He was instantly greeted by a churning sea of rock not a yard in front of his face. It shot by as if projected by an explosion. Before he could think, a mountain of boulders had settled by his doorstep.

Like most of his companions, Mr. Warrington was asleep at the time in a miner's shack. A noise resembling the beat of hail awakened him. He jumped to his feet as the cottage began to sway. Something struck his head, and he heard no more until the cries of children brought him back to consciousness. He found himself some forty feet from where his house had stood, partly buried under loose stone. Twenty feet away he saw his bed. His flesh was pierced by rocky shrapnel and his thigh was broken. But unlike most of his comrades he lived to tell his tale of a great disaster.

From such accounts, but especially from the mute

testimony of the countryside, this story was pieced together. Warm rains had filled the pores and crevices of Turtle Mountain with an unusual amount of ground water. A severe cold snap followed and froze some of the water. Weakened in this fashion, and perhaps also by blasting in the coal mines, the entire east face of the mountain suddenly broke away. In less than two minutes half a cubic mile of rock collapsed into the valley of Crow's Nest Pass. In a flash the mad avalanche buried a large part of the town and filled the valley to a depth that in places approached one hundred and fifty feet. It crossed the river and stopped only after it had climbed four hundred feet up the slopes of the hills on the far side of the pass.

Today the tourist can see the vast scar on Turtle Mountain as he follows a tortuous highway through the débris of the slide. Tumbled blocks of limestone as large as small houses lie on every side. Somewhere beneath are the bones of the miners to whom the dawn of one spring morning brought only the dark of an endless night.

IV

From the point of view of rocks in deeper zones, such homicidal performances of ground water are

but slight and superficial manifestations of its power. In the more inward realms it performs its major works. There, as closer to the surface, its endless prowling is not altogether baneful. It is a thief with redeeming virtues because it invariably robs Peter to pay Paul. Much of the mineral matter dissolved and carried away from one place is laid down in another. Once settled to a sluggish flow in the saturated zone, rain seepage loses most of the carbonic acid with which it destroys the rocks in its journey from above. Minerals filched in the descent are deposited in every convenient pore and crack. Similarly, the hot vapors that rise from below cool as they rise, and rest their burdens on the walls of fissures. Not only are the rocks thus favored considerably strengthened, but man gains some of the most valuable concentrations of ore within reach of his acquisitive fingers.

Such beneficence fades, however, when compared with the destruction dealt to regions where limestone formations prevail. Water carrying carbon dioxide converts limestone from the insoluble carbonate to the easily dissolved bicarbonate of calcium. Vast areas of the globe must pay tribute to this simple but relentless reaction. The rocks under many square miles of Kentucky, Tennessee, Indiana, Virginia, New Mexico, Yucatan, Indo China, the

Philippine Islands, and southern France, have been riddled as if by moths. Parts of Jugo-Slavia, east of the head of the Adriatic, have been practically unfitted for human habitation. Only too convincingly do regions such as these give proof that the water in the ground works blindly but well for the destruction of the earth.

Corruption of a limestone terrane proceeds according to a definite pattern. Subaerial agents of erosion strip away the protective covering of soil and vegetation in exposed places, and bare the underlying limestone to the corrosive touch of percolating rain water. Slowly solution widens cracks into fissures. Where two fissures intersect, a circular funnel-shaped hole takes form and grows steadily deeper and wider. Such sinks multiply on the face of the landscape with spread of the infection that is ravaging it.

Water draining downward through the sink holes descends still farther by insinuating its way through vertical fractures. Normally limestone is horizontally layered, and the planes between the layers offer additional channels. Ever gnawing at the rocks as it wanders through them, the water eventually excavates an intricate network of vertical shafts and horizontal galleries that honeycombs the ground from the surface down to the water table. Like Charybdis drawing mariners to their death, these

subterranean passageways draw the surface streams into their dark maze. Galleries grow to great caverns through which the sunken rivers flow, murmuring their muted song.

With time these streams descend to successively lower levels so that the air becomes relatively dry in the tunnels above. Water seeping through cracks in the roofs of abandoned caverns loses some of its carbon dioxide by evaporation as it drips to the floors and trickles down the walls. The deposits of calcium carbonate left behind create some of the most arresting effects in nature. Stalactites grow from the ceilings like icicles, stalagmites rise from the floors, columns resembling the pipes of an organ or the pillars of a classic temple may line the walls. In one place the delicate traceries of a Gothic window greet the explorer's eye, in another the misshapen forms of frozen ghosts, Gargantuan toadstools, and travesties of jungle beasts.

On either side of the Ohio River in Kentucky and Indiana is a realm of subterranean marvels. Tier on tier beneath the surface of the ground, one hundred thousand miles of open caverns drill the limestone rocks like the burrows of some gigantic worm. Above, the land rolls peacefully under the blessing of rain and fertility, giving little token to the traveler of the vast decay beneath his feet. If

he is a sharp observer, however, he will be puzzled by the scarcity of running water. Presently he arrives at a thicket of matted vegetation surrounding a dimple in the ground. The earth is damp, ferns and moss cling to the shaded stones. If a thunderstorm interrupts his investigations, he seeks cover in the bushes and watches the new-born rivulets course merrily to their doom in the hollow before him.

Should he visit Orange County, Indiana, he would see a stream with a story to tell. Lost River is unique in the possession of not only the usual surface channel but a subterranean channel as well. In flood the river flows above the ground throughout its course because the underground passageway is not large enough to carry the surplus water. But at most seasons it five times disappears through a series of sink holes, and five times rises again before finally settling to a normal career on the surface.

To see a river forty-five feet wide well from a hole in the earth is a queer experience, yet nothing short of a visit to the halls of the hidden kingdom can demonstrate the full strangeness of its wonders. The traveler may choose among many ports of entry. He can descend via Wyandotte, Marengo, or several other caverns in Indiana, but he will more likely follow the trail that fame has blazed to Mammoth Cave in Kentucky.

For many years Mammoth has been the queen of caverns in the western hemisphere. Although her superiority has lately been challenged by the new found Carlsbad Cavern in New Mexico, she still ranks high among the natural wonders of the world. Her galleries spread for miles at several levels, and vary from crevices too small to admit a man to great rooms as large as opera houses.

Behind him day fades to a tiny spot of light as the traveler presses into the gloom. The awe that such places have always bred in the imagination begins to creep over him as the passage widens and the corridors of a mysterious labyrinth radiate in all directions. Presently the tunnel rises and expands to a great hall that fancy readily converts to the nave of a medieval cathedral. Buttresses, columns, arched vaults, even the pulpit is there, and pervading all a mighty silence.

One by one, new spectacles appear in the shifting lights and shadows. Here the roof presses towards the floor and the traveler must crawl. There a vertical shaft leads to the awful dark of unknown depths. Peering into the abyss the guide expands with tales of suicide and heroism, tales doubtless taller than the pit is deep, but to which the sepulchral spirit of the place lends likelihood.

A boat is waiting on the bank of the "Dead Sea".

If the water is low the crusted rocks on the bottom gleam in an eery light. Blind white fish that bring forth their young alive lurk in the crannies. The boat seems to float in air as it pries into the secrets of each dark vista. Somewhere in the distance the river "Styx" is sadly murmuring.

All wanderings must sometime end. A ray of yellow light gilds the side of a narrow opening. The light enlarges and in it the leaves of trees take form. Stumbling forward the traveler is dazzled by his own world, which for just a moment seems less real than the world he is leaving. The scented air and the blue sky overwhelm him, and he breathes with conscious joy. He has seen death, and escaped.

V

Nothing in nature stands still. Sink holes and caverns once begun continue to grow. In time the roofs of the higher caverns may be worn so thin by solution and the falling of blocks that they collapse and bare their floors to the sky. In some places more resistant portions of the roofs may hold fast and form arches such as the famed Natural Bridge of Virginia.

Eventually a peculiar landscape evolves from the reticulation of sink holes and partly destroyed

caverns. Short ravines that abruptly dump their water into subterranean channels dissect the high steep elevations between the sinks. The country grows steadily rougher and more barren until ultimately it becomes an uninhabitable waste.

That part of south central France known as the Causses is a region well advanced on the road of this unhappy evolution. Its plateaus are grim pastures whose only flocks are the untamed winds. The limestone rocks have swallowed all but a few deeply trenched surface streams. The intervening areas are veritable deserts in the heart of a smiling land, where ridged and stony humps alternate with marshy depressions. Everywhere the rock is gaunt and bare, covered only by a thin and tattered garment of red soil made from the insoluble ingredients of the limestone. It is odd that in this land which men avoid today are caverns rich in mementoes of the Neandertal men of yesterday.

We must look farther east, however, if we are to see the full picture of despoliation on a limestone terrane. The vessels that came to Venice in the days of its glory, the very piling on which the city was built, were made of logs cut in forests that flourished in the Karst district across the Adriatic. Ruin was not slow in following deforestation. Rain quickly washed the soil away, and solution in the limestone

rocks below brought destruction to the surface. Today the Karst is a desolate land, all but forsaken by God and man. Even the goats that once roamed in countless herds have grazed to the brink of extinction.

Because of the exceptional purity of much of the limestone in the region, sink holes have grown to enormous size. Some of them are more than half a mile in diameter and three hundred feet deep. Most of what is left of the soil now clogs the bottom of these bowl-shaped depressions. It is here that the scattered human population ekes out a meager existence. Made from the clay impurities that defied solution, the "terra rossa" is fertile despite its thinness.

Between the sinks the rock juts in sharp blades resembling the fissured surface of a glacier. The country is rough enough in places to forbid any trespass. Rain escapes quickly into the caverns below, so that broad tracts are devoid of surface streams and almost devoid of vegetation. Out of crevices one hundred feet deep comes the burble of hidden water. At rare intervals the underground streams dare issue from their gloomy haunts to flow for a space through steep-walled valleys and then to vanish beneath the limestone cliffs. At such points the dauntless inhabitants build their reservoirs against

the heat of summer. In winter the "bora" howls out of the north with additional maledictions for an accursed land.

Tier by tier the caverns underlying such a region are destined to collapse. The land surface will melt away, literally dissolved in water. When the roofs of the lowermost caverns have fallen, layers of less soluble rock will begin to appear, and streams will begin to trench the fresh surface in normal fashion. Here and there remnants of the limestone, rotten and doomed, will rise in forlorn isolation above the general level of the new land. Then these too will vanish. Victory for the waters that work in the dark will be complete.

V

Battalions of the Frost

SINCE a time so remote that imagination falters in the attempt to conceive it, the sun has mothered her brood of planets. The freedom of mighty wanderings she has granted them, but only within the limits she has set. Through unnumbered eons she has preserved the integrity of her family circle against all the lethal attractions of space.

For some two billion years the earth has known the ministrations of the sun. Two billion times under the guidance of that friendly star she has closed with no dire misfortune the vast ellipse of her orbit. And the creatures who constitute her chief distinction in the universe came to her because the sun first filled her lands and waters with warmth and light. They have endured because the sun has endured. Had solar radiation failed for a moment, all plants and animals would have perished at their mother's breast.

There have been times, however, when the sun has nearly failed, and the cold of space has reached with fatal fingers toward the earth. Ice bred in an unfriendly air has piled high on more than one un-

happy upland, slowly but widely to expand under the inexorable pull of gravitation. Good green lands have blanched to frost-bound deserts, their creatures scattered or slain. Of all the vandals that trample the face of the globe, few have been more successful than ice in the attempt to alter its expression.

Few, however, have been more erratic in their operation, more mysterious in their coming and going. Through all the long eons since the earth began the record of her career, mild climates have preponderated in the history of polar and tropical regions alike. Glaciation, though repeated on her scroll, represents but temporary deflections in the normal flow of events. During most of the past there were nowhere any extensive fields of ice that long endured.

Sporadic in their distribution, irregular in their recurrences, glaciers have quickly spent their evil vigor on the lands and then departed. Even in those ages when large tracts suffered their devastating tread, much of the earth's surface was not chilled to the congealing point of water. Although the weak succumbed, life somehow braced its latent energies so that the strong might march onward to better days. Glaciation at its worst is a repeated but evanescent curse, disposed as surely to disappear as to reappear. Even in its severest visitations it has ruled but briefly and incompletely, with relatively short epochs of cold

and ice punctuated by stages of interglacial mildness.

Why glaciation should be so fleeting and unstable, why it should one time settle on polar regions and another time on the tropics, why indeed it should occur at all, are questions that have educed an impressive tonnage of literature but no impressive answers. The sky, the air, and the rocks have been combed for solutions of these riddles, but with all our vaunted knowledge, the cause of glaciation remains one of the outstanding enigmas of the globe.

Investigators, riding the wild horses of private preference, have proposed and defended an arresting array of contradictory hypotheses. If anything has come from more than half a century of speculation it is that no one hypothesis can explain the problem. Somewhere in the maze of astronomic, meteorologic, and geologic conjectures may lurk the synthesis that will solve all. It is far more likely, however, that widely differing combinations of causes brought about the widely differing manifestations of glacial phenomena preserved in the record of the rocks.

Croll, in one of the earliest attempts to explain ice ages, built an elaborate hypothesis on the periodic elongation of the earth's orbit. When the orbit is nearly circular, summer and winter are of nearly equal duration; when very elliptic, winter may be a

month or more longer than summer. Croll assumed that during each succession of long winters more snow accumulated than the brief summers could dissipate, with glaciation the inevitable result.

Because of the precession of the equinoxes, the relation of summer and winter in the northern and southern hemispheres changes approximately every thirteen thousand years. The location of the ice must consequently change. When the north is enduring a glacial climate the south must be basking in interglacial warmth, and *vice versa.* Croll elaborated a mechanism whereby air and ocean currents might abet such rhythmic alternation of glacial conditions, but he failed to show that the alternation had ever occurred. It is now certainly known to the contrary that during the last great ice age all continents suffered decided drops in temperature at the same time. It is also believed that glaciation has not come on every occasion of extreme eccentricity in the earth's orbit, but less frequently and regularly.

Another hypothesis attempts to correlate the periods of glaciation with the time of greatest tilt in the axis of the earth, but here again the known facts are stubborn and refuse to fall in with the calculations. Nor does the assumption of a shifting axis any better satisfy the requirements of history. If the south pole had been located in the middle of the

Indian Ocean, the extensive glaciation of Australia, India, and South Africa during the late Paleozoic Era might be explained. Unfortunately South America would have lain in the tropics under this scheme, yet it too was heavily glaciated at the same time. Furthermore, the north pole would have been in Texas near the Mexican line where no slightest evidence of glaciation exists.

Undaunted, however, the theorists keep to their looms. Most lurid of all recent geologic imaginings is the Taylor-Wegener hypothesis of continental drift. One phase of this hypothesis postulates an ancient continent of Gondwanaland, larger than Eurasia and uniting India, South Africa, Australia, South America, and Antarctica in one colossal mass of land. On such a super-continent the north pole might have been so placed that most of the known regions of late Paleozoic glaciation would have fallen within the forty-fifth parallel. Later, Gondwanaland is claimed to have disintegrated, India moving thirty-five hundred miles to the north, South Americe two thousand miles to the west, Antarctica fifteen hundred miles to the south, and Australia one thousand miles to the east.

Just how these movements in all directions at once might have been motivated is a more difficult problem than any of the problems the hypothesis at-

tempts to answer. The migration of the poles, so freely implied by the concept, is also highly doubtful. The earth is a gyroscope with a strong tendency to keep its axis pointed in one direction. A sudden shift would probably wreck the world as promptly as the assumption of such a shift should wreck a preposterous conjecture.

Ellsworth Huntington sees variations in the radiation of the sun as the chief shifter of terrestrial climate. Although there is no proof that variations of sufficient magnitude to cause glaciation, or with a rhythm that coincides with the irregular spacing of ice ages, have ever occurred, the view is challenging. Vaguer is the suggestion of certain astronomers that if the solar system had ever wandered into a region of dark nebulosity, the sun might have been temporarily screened and the earth cooled. Without proof that such an event ever took place, the idea fails as a satisfactory working hypothesis for the cause of glacial periods.

It is not necessary to leave the earth to spin the web of a glacial hypothesis. Indeed, some of the most intriguing of them never rise above the atmosphere. The carbon dioxide in the air is known to resist the passage of heat, both to and from the earth. It is the major check on sudden extremes of weather and climate. Arrhenius was the first to argue that any

significant decrease in the carbon dioxide content of the air would promptly precipitate an ice age. Many agencies rob the atmosphere of this gas. Because growing plants built it into their bodies it has been suggested that the luxuriant coal forest of the Carboniferous Periods helped bring about the ice age that followed. Chamberlin has urged that when the lands stand high the rocks absorb large quantities of carbon dioxide, and might thereby induce glacial conditions. Unfortunately this hypothesis does not account for the relatively rapid and repeated changes from glacial to interglacial conditions so typical of the better known ice ages.

The fact that dust shot into the air from volcanoes impedes solar radiation has fathered yet another explanation. Humphreys has urged repeated volcanic eruptions as a probable cause of glaciation. Carbon dioxide, however, is also vented by volcanoes, and a large efflux of this gas might be expected to bring on a mild climate. A sufficiently zealous adherent might use the hypothesis to account for any climate imaginable, but the more skeptical suspect that the opposing effects of dust and gas must counteract each other.

Elaborate hypotheses have been erected on the assumption of a gradually cooling globe, on the probability of alteration in the direction of ocean cur-

rents, on the fact of changing continental elevations. But one by one even the most ingenious guesses fail. Not one accounts for the totality of known facts, although several contribute fragmentary explanations. Most are not worth the effort and debate they have occasioned. Glaciation towers inscrutably over them all, one of the supreme mysteries of nature.

II

Had man been born into the world a few million years earlier, his ignorance concerning the effects of glaciation would long have matched his present ignorance of its causes. Should his coming have been much delayed, he might never have gained any considerable knowledge of the mechanics of earth sculpture by ice. Born as he was with the dawn of what appears to be the greatest ice age the globe has ever suffered, he has lived to witness and to study, if he desires, its dying throes. Greenland and Antarctica are still buried under sheets of ice, floe ice still jams the northern seas, glaciers still cling to hundreds of lofty peaks, some of them squarely astride the equator. Even the temperate zones are not so temperate, but must wrestle each year with winter. In many places the story of ice may be read before the ink has dried.

The loosening of soil and the blasting of rock by freezing water only suggest the vast sculptural potentialities of ice. Rivers victoriously booming when they sunder the chains of winter do not even suggest that such chains are not always so easily shattered. Icebergs adrift with ghastly menace give little token of the far greater power of the parents who turned them loose, whose pleasure is the destruction not of ships and men but of the earth itself. To learn the full strength of the frost and its significance in the destiny of earth, one must go to the glaciers. One must go to the lands where rivers and seas of ice are yet at work, and to the lands where the scars of their vengeance have survived their death.

Glaciers are children of the cold, born only in regions where the sun of summer fails to destroy all the snow of winter. Today the base of the zone of permanent snow rises from low elevations in polar lands to a height of eighteen thousand feet where such a mountain system as the Andes crosses the equator. The glaciers that yet endure on earth were born above this snowline, and die when they venture far below it.

By a strange paradox, glaciers are also children of the sun. Heat from that star evaporates ocean water and loads the wandering air currents with moisture. Highland barriers facing these winds force

them to rise, cool, and drop their burdens. Regions without uplands are also without glaciers, regardless of their frigidity. Siberia is one of the coldest lands on the globe, but it lacks glaciers because it lacks the means of trapping the moisture necessary for their nourishment.

In the north temperate zone where prevailing winds are westerly, the ranges that face the setting sun gain most of the moisture. Thus it is that in North America the Sierras and the northern Rockies waylay the wet breezes of the Pacific Ocean, and consequently harbor the glaciers of that continent. Similarly, the Alps in Europe come upon their plethora of ice by draining the clouds blown westwardly off the Atlantic. In the tropics where the wind pattern is reversed, the foci of glaciation are likewise reversed. There the mountains flanking the eastern coast lines attract the glaciers. In South America no ranges are so situated, so the winds from the Atlantic Ocean travel westwardly far over the forests of Brazil, and are not sapped of their contents until they strike the towering ramparts of the Andes. So it is that although a continuous belt of mountain glaciers lines the westward edge of the two Americas, the northern ice tongues feed on moisture from the Pacific, the southern on moisture from the Atlantic.

There is reason to believe that the conditions which engender both the birth and the death of glaciers must creep upon the earth through a series of exceedingly gradual climatic variations. So delicate is the adjustment of temperature and moisture today that no very great alteration of climate would work spectacular changes. It has been estimated that if the average yearly temperature of the Scottish Highlands should drop but 3°F., small glaciers would be born. A comparable rise in temperature would doubtless quickly destroy the refugees of the last ice age that linger in the mountain fastnesses of the temperate zones.

One of the strangest aspects of human history is the changing attitude of men toward the world they inhabit. There was a time when mountains made no general appeal to the love of beauty and adventure, when fear of the devil stilled the innate curiosity of the mind. But in 1760, de Saussure offered a prize for the discovery of a way to the summit of Mont Blanc, and thereby opened a way to the appreciation and understanding of mountain scenery. Some who followed this trail accepted mentally as well as physically the challenge of the snow and ice. Out of their curiosity the modern science of glaciation was born.

It is common knowledge today that mountain gla-

ciers are truly rivers of ice which flow over the beds of their valleys. A century ago this fact was just beginning to be suspected. In 1827, the Swiss Professor Hugi built a small cabin on the middle of the Unteraar Glacier in the Alps, and soon discovered that it was slowly creeping down hill with the ice on which it rested. In eleven years it had moved 4712 feet, at an average rate of about a foot each day.

It remained, however, for Louis Agassiz to make the first scientific observations on glacial movement. In 1841, he drove six sturdy piles ten feet into the ice of the same glacier, spacing them equally in a straight line between the valley walls. Shortly it became apparent that the line was sagging downstream. After a year Agassiz carefully measured the displacement of the pegs. The first stake had moved 160, the second 225, the third 269, the fourth 245, the fifth 210, and the sixth 125 feet. It was obvious that the ice was moving, the middle almost twice as rapidly as the sides.

At the same time the British Professor Forbes came to similar conclusions concerning the mighty Mer de Glace on Mont Blanc. For many years he continued his researches on several Alpine glaciers, until he had gained much precise knowledge about the rate of glacial movement. Presently a horrible

episode made all Europe aware of the accuracy of his observations.

One fateful August day in 1820, a party of five climbers and eight guides had attempted the ascent of Mont Blanc. Near the top of the peak the weight of their bodies started an avalanche of snow and ice that swept the unlucky thirteen down the mountainside. Ten of the men were able to exhume themselves, but the three leading guides were carried to their death in a deep crevasse near the head of the Bossons Glacier. Professor Forbes estimated that after some forty years the bodies would be returned at the foot of the glacier. In August 1861, just forty-one years after the catastrophe, the prediction was gruesomely verified. In a crevasse near the foot of the glacier, far from the site of the accident, the dismembered heads of the three guides emerged from their frozen tomb. During the four years that followed, other parts of the bodies appeared in the same place, along with shreds of clothing, rope, and alpenstocks.

The glaciers of the Alps, like glaciers elsewhere, undergo alternating spells of vigor and lassitude. These pioneer observations were made during a period of temporary vigor; at present few Alpine glaciers move as rapidly as a foot a day. Certain Alaskan glaciers, on the other hand, move forty feet on

a summer day, and a few Greenland glaciers attain to the prodigious speed of sixty feet a day. But these are clearly exceptional. The death knell of the ice age has sounded; once more the earth looks toward more genial times. The glaciers that yet remain may enjoy their momentary triumphs, but they may not elude the shadow of impending doom.

III

Most scientific discoveries raise more questions than they answer, and those of Agassiz and Forbes were no exceptions. Demonstration of glacial movement led to the difficult problem of how such movement is accomplished. How does ice, which is a brittle solid under sudden pressure, move with the apparent plasticity of molasses under pressure slowly applied and long sustained?

In 1893, Dr. P. Jules C. Janssen, who understood the stars but not the glaciers in their courses, built an observatory on the ice-bound summit of Mont Blanc. No sooner was it erected than it began to sink. Although twenty-three feet high, the roof became flush with the snow in seven years. Every summer for the following six years workmen opened an avenue to the top story. By that time the structure had sunk so far into the icy quicksands of its founda-

tion that even the ardent Dr. Janssen was satisfied to abandon it. Three years later, when only the top of the tower was visible, the building was salvaged for firewood. It was found to have slid down the Chamonix side of the mountain, with the trend of the summit snowfield.

The feeding ground of the typical mountain glacier is just such a summit or subsummit snowfield. There the snows of winter each year linger a little longer until the larger drifts survive the bombardments of the summer sun. Powdery flakes nestling in the hollows at the heads of ravines accumulate until the lower layers are compressed into the hybrid combination of snow and ice known by the French as névé. Through processes not yet fully understood the snow is molded under the shifting pressures until it acquires a granular texture suggestive of interlocking hailstones.

So long as more snow falls in winter than melts in summer, the névé crawls down the slopes at the command of gravity, presumably by the alternate melting and freezing of the surface of the pellets. Typical blue glacial ice begins to protrude along the lower margins. Fattened with time beyond endurance of their own weight the nascent glaciers spread sidewise and creep farther and farther down the declivities at their feet. In maturity they usurp the

valleys of rivers. The more successful ones flow out of the mountains and broadly over the plains below before the sun makes an end of their wanderings.

The tongues that drain the snowfields consist of granules somewhat larger than those of the névé ice, and rather more intimately intergrown. Although they move more rapidly than the névé, they move in the same fashion. Seeming to flow with the ease of a viscous fluid they remain in reality essentially solid throughout. Irregularity in their beds and friction along their sides develop great cracks in the surface that quickly dispell this illusion of fluidity for the climbers who must negotiate them. The stern maws of such abysses hungrily await the unwary step. History can testify that death lurks in the heart of glacial crevasses. W. D. Johnson, who dared to explore the bottom of one, knows that the answer to a great riddle may possibly lurk there too.

This dangerous exploit occurred near the beginning of the twentieth century and near the end of a long controversy over the effects of glaciation on the landscape. Some scientists had argued that glaciers protect the rocks over which they move. Others had defended the view which is now so well established, that glaciers are merciless engines of destruction. Johnson was impressed by the fact that the heads of mountain glaciers nestle in amphitheaters

which have no counterpart in unglaciated ranges. He suspected that in some fashion the glaciers themselves must excavate these depressions. Consequently he allowed himself to be lowered into the crevasse that separates the glacial tongue of the Mount Lyell Glacier in the Sierras from the snowfield that feeds it. Soberly he reported his findings:

"Among the numerous crevasses or schrunds of several diverse systems sharply lining the snowy surface upon which I looked down as upon a map, one master opening, the bergschrund of the Swiss mountaineers, paralleled the amphitheater wall, a little out upon the ice. In detail it was ragged and splintered, but its general effect was that of a symmetrical arc. I had already in mind, vaguely formulated, the working hypothesis that the glacier makes the amphitheater; that it is not by accident that glaciated mountains, and such mountains only, abound in forms peculiarly favorable to heavy snowdrift accumulation. My instant surmise, therefore, was that this curving great schrund penetrated to the foot of the wall, or precipitous rock slope, and that a causal relation determined the coincidence in position of the line of deep crevassing and the line of the assumed basal undercutting.

"The depth of descent was about one hundred and fifty feet. In the last twenty or thirty feet, rock

replaced ice in the up-canyon wall. The schrund opened to the cliff foot. I cannot say that the floor there was of sound rock, or that it was level; but there was a floor to stand upon and not a steeply inclined talus. It was somewhat cumbered with blocks, both of ice and of rock; and I was at the disadvantage, for close observation, of having to clamber over these, with a candle, in a dripping rain, but there seemed to be definitely presented a line of glacier base, removed from five to ten feet from the foot of what was here a literally vertical cliff.

"The glacier side of the crevasse presented the more clearly defined wall. The rock face, though hard and undecayed, was much riven, its fracture planes outlining sharply angular masses in all stages of displacement and dislodgment. Several blocks were tipped forward and rested against the opposite wall of ice; others, quite removed across the gap, were incorporated in the glacier mass at its base. Icicles of great size and stalagmitic masses, were abundant; the fallen blocks in large part were ice-sheeted; and open seams in the cliff face held films of this clear ice. Melting was everywhere in progress, and the films or thin plates in the seams were easily removable.

"These thinning plates, especially, were demonstrative of alternate freezings and thawings, in short-

time intervals, probably diurnal. Without, upon the cirque or amphitheater wall, above the glacier, such intervals would be seasonal. Thus, apparently, to generalize from observations at a single point, the arc of the bergschrund foot, and the coincident arc of the cirque-wall foot, is a narrow zone of relatively vigorous frost-weatherings. The glacier is a cover, protective of the rock surface beneath it against changes of temperature. Probably the bed temperature does not fall below that of melting ice. Hence, if (in summer) the bed at the wall foot is exposed through the open bergschrund, to daily temperature changes across the freezing-point, frost weathering must be sharply localized. The glacier will be efficient as the agent for débris removal; the result, therefore, must be quarrying and excavation, and basal sapping."

In other words, the master crevasse that forms where a glacier pulls away from the snowfield marks a sore on the mountain that cannot permanently heal so long as the glacier exists. Every summer the great crack opens and the rocks at the base fester with the infection of the frost. Like a scavenging beast the ice on the lower face of the crevasse swallows both the rocky products of disintegration and the ice that enters from the snowfield above. Slowly it moves its fattened hulk downhill. Every winter snow fills the schrund and temporarily heals the wound, but

with spring the old illness returns. Each season a little closer to the headward wall the mighty cleft reopens, and frost quarrying bites into the rocks below. Thus gradually the glacier both lowers its floor and recesses its walls, insatiably eating into the heart of the range.

Although some phases of cirque sculpture are yet unknown, Johnson's intrepidity and shrewdness revealed something of the mechanics of glacial erosion in the belt where it is most effective. They led to a better understanding of the violence that hides beneath the calm white face of moving ice.

IV

Glaciers of many varieties still cling to the mountain massifs of the earth. Far north and west of Norway lies the unhappy island of Spitzbergen, where ice yet thrives in a world that has decreed its death. Indeed, the gusto of a glacial heyday lingers over the mountains of Spitzbergen where only the highest peaks and passes rise above the frost-imprisoned valleys.

Scarcely less impressive are the piedmont glaciers of northern Alaska and the southern Andes, consisting of ice that flowed from mountain canyons to coalesce into widespread aprons on the plains below.

The Malaspina Glacier of Alaska is such a composite ice sheet with a front of seventy miles on Yakutat Bay, and a landward extension of more than twenty miles. Heaps of rock riven from the walls of its feeder valleys have spread broadly over its outward margin, where a forest rides upon its back. In lower Alaskan latitudes are less well nourished yet still buxom glaciers such as the Taku, which expand at the feet of their valleys, but not sufficiently to merge with their neighbors.

The Himalayas have glaciers that show unmistakable emaciation, yet preserve withal something of their old vitality. Although their fronts have melted back from the mountain forelands, their side valleys continue to feed ice into the main channels. Most Alpine glaciers represent a stage of further depauperization, with their tongues protruding only a little from the amphitheaters at their heads. In Glacier National Park the final stage of wastage is exhibited. Shriveled glaciers hang like dying flies from walls that refuse them further nourishment.

Though even the most vigorous of living glaciers can only suggest the potency of ice during the height of an ice age, much can be inferred from them and from regions where dead and dying brethren have left their imprint on the lands. From these Johnson and many other investigators have pieced

together a story of glaciation, a story perforce read backwards and not without its missing pages, yet seemingly true and complete in fundamentals. It is the story of a master sculptor whose life is an eon of unnumbered days, whose studio is the broad arch of heaven, and whose clay is the loftiest mountain ranges on the globe.

The Bighorn Range in Wyoming was never a favorite spawning ground for glaciers. Even at the peak of the recent ice age, little moisture gained access to the Bighorns, and broad expanses of their summit lands were spared the malice of moving ice. Today such glaciers as existed there are all but gone; scarcely more than a modicum of modestly enhanced snowdrifts remain. Yet in these drifts, as F. E. Matthes has shown, is a suggestion of the pre-natal growth of glaciers.

Glaciers are born of snow nestling in hollows on the higher levels of a mountain range. Each summer day the drifts are belabored by the sun until meltwater renders soft and soggy the ground beneath them. Each night this water freezes in the crevices of the bedrock, cracking and ultimately pulverizing it so that the rills of daytime melting may carry some of the débris away. The drifts that survive the onslaught of many summers slowly settle into niches which are partly inherited and partly the handiwork

of the snow itself. As glacial climate tightens over the land, the day must come when gravity will draw the waxing snowbanks to lower levels. It is then that the drifts become the snowfields of incipient glaciers, and the niches embryonic cirques.

Presently outflow demarks the glacial tongues from the névé fields that nourish them, and the work that Johnson elucidated begins at the bottom of the master crevasses. While the heads of the growing glaciers gnaw their amphitheaters ever more deeply into the range, their feet expand below into the valleys that rivers have carved, remodeling them to their own design. Freezing to blocks of rock dislodged by frost action in the cankered belt of the bergschrund, plucking other blocks from their beds, they load themselves for further work. Ever gouging, grinding, scraping, polishing, and scratching the bottoms and sides of their harassed channels, they eventually wear away the major irregularities. V-shaped runways of ancient rivers are slowly modeled to the U-shaped avenues which are the chief low-level forms of glacial sculpturing.

In time the headward-growing amphitheaters invade the upland from opposite sides until an airplane view of the range resembles a crinkled mass of dough from which a giant hand has punched out a double row of biscuits. Continued growth all but destroys

the surface of the original upland. The divides between cirques approaching the crestline of the range from either side are sharpened to knife-like ridges that cut the sky with sheer and pinnacled grandeur. In similar fashion cirques growing laterally on the same side of the range reduce the divides that separate one from another. Finally each cirque becomes sharply bounded on three sides by narrow, steep-walled palisades.

Many of the spectacular features of a maturely glaciated upland may be seen in such a region as the Alps, where not a little snow and ice have lingered to the present. Wherever the heads of two cirques have closely grown together, the middle of the intervening ridge is characteristically lowered to produce the sharp-edged gap so helpful to mountaineers who climb over the top of a glaciated range. Where three or more cirques converge, a pyramidal remnant of the original upland may rise precipitously above the general level. Thus tower the Jungfrau and the Matterhorn, defiant of all the forces that beat upon them, lonely but triumphant in a world enslaved.

In other ranges where the ice has almost died away, the glacial landscape appears with the full glory of its details. The stern gaunt beauty of sky-line crags melts below into a sea of flowered meadows and forests. Emerging from their cirques the ice-

carved valleys incise the mountainsides in broad deep parallel grooves. Everywhere they display the earmarks of their origin. Differential action of the ice has altered the smooth and regular river-worn profiles of their beds to colossal flights of stairs. Little tarns of limpid amethyst nestle in the dimpled treads. They are strung to the foot of the range like so many beads in a rosary, joined by cascades white with the hurry of descent.

Tributary valleys whose mouths were cut back by the ice in the main valleys, and whose own ice could not cut rapidly enough to keep their floors accordant with the floors into which they flowed, are now hung high on the sheer walls of the major defiles. The streams that came back to them with the death of the ice, flow happily enough until they meet the points of juncture with the main channels. Instead of smoothly yielding their waters as of yore, they must now plunge to the valleys below. So far may be the fall that the water breaks up into mist before it reaches its destination. The unexcelled beauty of such falls as these is rapidly making Yosemite the most popular national park in the United States.

The sharpening of peaks and the deepening of valleys produce a mighty litter of rock débris. This the waning ice tongues spread in serpentine ridges

along the lower reaches of the valleys or drop in shapeless heaps along the mountain fronts. Over the hummocky surface of these moraines nature flings the carpet of her forests. With consummate artistry she frames the pictures that are among the noblest in her gallery.

V

A century ago nobody suspected that glaciers had once trod the lowlands as well as the highlands of the northern hemisphere. Early in the nineteenth century the sand, gravel, and boulders that drape Europe like a tattered shawl had caught the eye of the curious, and had elicited a variety of speculations. The boulders of red granite strewn over the plains of Germany were unlike any rocks in the vicinity, but exactly like the red granite hills of Sweden. Piously in 1815, Buckland invoked the deluge of Noah for an explanation. Similar deposits in North America begot similar fancies. Two decades later the illustrious Sir Charles Lyell suggested that these "erratics" had not been dropped by water, but by icebergs drifting out of the polar sea. Accordingly he rejected the word "diluvium" by which they and the associated sand and gravel had been known, and dubbed the deposits "drift". This term has quaintly survived the speculation that mothered it.

In the summer of 1836, Louis Agassiz became convinced that the glaciers of the Alps had once extended far beyond their present boundaries. Leagues from any living glacier he found both moraines and striated bedrock which nothing but moving ice could have formed. In the British Isles where no glaciers of any sort exist, he found similar evidence of glacial deposition and erosion on every hand. In 1840, he proclaimed his revolutionary discovery to a startled and dubious world, "that not only glaciers once existed in the British Islands, but that large sheets of ice covered all the surface".

Despite all manner of learned ridicule, Agassiz continued his studies until he was certain that the whole of northern Europe had once been plowed by continental ice sheets, that these and not icebergs had given birth to the drift. So inescapable were his conclusions that one by one his opponents capitulated. In 1846, he announced that northern North America had suffered a simultaneous invasion by ice sheets. As in Europe the evidence was overwhelming. The "ice age" became a recognized chapter in the latter annals of the earth.

The research of three quarters of a century has filled out the story that Agassiz read in the rocks. It is now known that at one time or another during the last million years, approximately one-fifth of the

land area of the globe was buried under sheets of moving ice comparable to the frozen caps of Greenland and Antarctica. In Europe, glaciers born in the Scandinavian mountains spread over the Bothnian plains of Sweden on the east. There the ice piled to the thickness of a mile, and flowed in all directions until two million square miles of Europe was submerged. In North America, similar ice sheets gathered about centers in Labrador, north central Canada, and the northern Rockies, and flowed out over four million square miles of the continent.

So thick were these glaciers that the slope of their surface rather than the slope of the ground beneath them determined their movement. They rode at will over such mountains as the Adirondacks, leaving on many a peak the telltale grooves and scratches that prove it. North of the Great Lakes lies a far-flung region of lesser lakes, each one occupying a hollow scooped out by the ice. Raped of soil and vegetation by the passing glaciers, the stark land fades into the mist of unknown and unsought horizons.

What Canada lost, the upper Mississippi Valley gained. South of the Great Lakes, which also lie in lowlands gouged out by the advancing lobes, the ice grew sluggish and dropped its stony loot along the southern margins. From New England to the Rocky Mountains the débris is now strewn in haphazard

hills and ridges and outwash plains, in places to depths of six or seven hundred feet. Rivers were turned from their courses or ponded in vast sloughs. Shallow Lake Agassiz, five times the size of Superior, took form on the plains of North Dakota and Alberta with the northward retreat of the glaciers. When the ice finally vanished completely, the impounded water drained into Hudson Bay, leaving flat and fertile fields which have since become the bread basket of two nations.

An interesting record of the last days of the continental glaciers was left in the lakes that formed in front of their shrinking margins. Clays made of the finer rock material gathered by the ice were deposited in beds of alternating dark and light layers. The light layers are thought to be the silt that settled in summer when the ice was rapidly melting. The dark layers of finer greasy material are believed to be the winter droppings from the quiet water after the surface had frozen.

Thus like tree rings the banded clays record the passing years. With retreat of the ice and the lakes that clung to its margins, the clays were laid down like shingles from south to north. Ingeniously piecing together the record of beds in scattered localities, Baron de Geer discovered that southern Sweden emerged from the ice about thirteen thousand five

hundred years ago. He calculated that the retreat began in northern Germany some twenty-five or thirty thousand years ago. Similar methods yielded approximately the same conclusions for North America.

Agassiz and others of his day saw in these Pleistocene ice caps symptoms of a planet slowly dying of cold. The lifeless moon, whose heat was thought to have entirely oozed away, seemed to mark the goal for which the earth herself was destined. But later it appeared that at the close of the Paleozoic Era, many million years before, the southern hemisphere had suffered a severe ice age and had somehow survived. Still later the indubitable evidence of an extensive ice age in southern Canada was unearthed from some of the oldest rocks in the geologic record. It would seem that whatever end may await the earth, it will not take the form of drowning in a sea of ice.

VI

Yet ice of mysterious and ominous propensity will doubtless continue to harass from time to time not only the earth but also the creatures who dwell on her surface. Indeed, if the past be any token of the future, ice will decide the fate of myriad lives. For over and over again it has fallen on the haunts of

plants and animals, a deadly scourge to the weak, a mighty challenge to the strong.

The supreme event in the latter annals of the northern hemisphere was the conquest of eight million square miles of land by the Pleistocene ice sheets. In both Europe and America the deposits of drift tell a tale of vacillation. Four times at least the glaciers marched to the south and four times retreated before their final demobilization. Prior to their coming a rich and varied society inhabited a friendly northern world. Driving equatorwards like tidal waves the glaciers turned that world into the most vast and most uninhabitable desert in the history of the earth. Every advance of the ice forced arctic plants and animals to the south, crowding them into bloody competition with creatures of the invaded lands; every retreat brought a returning surge. Because the interglacial stages were long and warm, tropical plants and animals migrated far to the north where they lingered—until the ice returned.

Creatures everywhere, in fact, were sorely tried by the violent changes in climate that attended the alternation of glacial and interglacial conditions. Some of the mammoths and rhinoceroses grew fur for a new way of life, and fought it out near the edges of the ice. Many other animals wandered far from their native lands, never to return. The musk

ox roamed to unglaciated regions of the remote north; the horse, the tapir, the camel, the lion, and a host of others settled permanently in the south. Not a few, too weak to stand the strain of ceaseless migration, died without issue. Others survived but were profoundly changed. Even South America and Australia, which felt only the breath of the arctic demon, saw the passing of the giant sloths and marsupials. In the seas, where melting ice brought lowered temperature, half of all the shelled inhabitants foundered into the mud.

Only two land animals in the jostled hordes appear to have adjusted themselves to the topsy-turvy Pleistocene world: the two-legged mammal with ingenuity in his head, and the four-legged mammal that follows him around. Together they roamed the earth and somehow managed to thrive in the face of every adversity. These adversities, however, played a significant rôle in the history of both. Although the story of the rise of the former is largely conjectural, no one can doubt that cold was a potent and continual influence. Even before the birth of the mighty ice caps—in Asia during the latter days of the Tertiary Period—cold was already beginning to model the features of humanity.

There, it would seem, some million years ago, the ancestors of mankind were grappling with new

problems in a new world. Their arboreal homeland had been all but destroyed by the creeping catastrophe of the Himalaya uplift. Trees and fruit had been driven to the tropics by the increasing cold and dryness. Relatives, embarrassingly simian in philosophy and physique, escaped to the south before the rising ranges made a prison of northern Asia. Their descendants still haunt the tropics, chattering content in an inexhaustible paradise of bananas. The ancestors of man forfeited such amenities by lingering too long in the northland. Folly thus first recorded itself, and a precedent was established for a major human avocation.

Through the long ages that followed, the most significant chapters in the story of mankind were written. The human body emerged. Freed from the trees, feet were able to explore, hands to examine, and brain to attack the problems of the ground. Primitive men slowly learned the arts of self-protection and hunting. Spurred ever by the menace of ice, they discovered the use of fire and clothing. Thus armed against both foe and climate, they were free to wander with relative safety, to invent communal living and articulate speech, to nourish the germs of civilization.

Such blessings, however, were not easily or rapidly won. The fluctuating margins of the ice kept

men in continual migration. The weaklings among them could not have survived the levies of such a life. When the final thrust of the continental glaciers rose to the fulness of its tide, all of northwestern Europe lay under the ice; and vast regions beyond the margins must have been too cold and stormy for human habitation. Northern Asia, although unglaciated, was likewise cold and unfriendly. Those inhabitants of both continents who had managed to endure the vicissitudes of previous climatic unrest were once more crowded to the south. Already weeded of weaklings, they were weeded again. For with the waning of the ice sheets, the green lands of refuge in North Africa, Arabia, and Central Asia began to wither in the sun; men were forced to move again. Some of the desert peoples of Asia wandered into China and India; others found their way to the oases of the eastern Mediterranean where they mingled with the survivors from Europe. From these children of hardship and struggle came the earliest civilizations, whose legacy of inventions and discoveries humanity can never exhaust.

With continued amelioration of climate, the valleys of Egypt and Mesopotamia failed to provide the stimulation necessary to progress. Slowly their civilizations drooped; the ever restless sons of men began to wander away. With improved ability to battle

the forces of a fickle world they roamed to the north in the wake of the retreating ice. Ever and ever a little farther north successive civilizations flowered: in Assyria, Palestine, and Phoenicia; in Greece; in Rome. By medieval times the star of empire had risen as far as France. Today its light falls brightly on the British Isles and Scandinavia, and on comparable latitudes in other lands.

Possibly, as Stefansson believes, it will continue to rise. For the time being, however, civilization will doubtless be content to linger on the broad bosom of north temperate lands. There on the rich soils that were heaped high by the ice sheets near their southern margins, and under a climate that smacks a little but not too much of the past, men may be expected to continue to thrive until the ice returns. No one, of course, can surely know just when or where this will happen. One can only know that history is fond of repetition. The great white faces of Greenland and Antarctica symbolize both the past and the future. Silently they proclaim the inexorable and enduring power of ice which grinds all opposition to dust, and which has no mercy for stone or man.

VI

The Hungering Deep

LIKE the turbulent crowd at the rim of an arena, the sea surrounds the lands and awaits the issue of combat. Fretfully the colossus chafes at the margins of battlefields it is eager but impotent to enter. Well might it know, were it sentient, that some day it would claim from the victors the spoils of their victory. For into its ravening maws the winds and the streams and the glaciers must some day drop their loot. Like death in the world of the living, the sea marks the end of striving in the world of the dead.

But the sea is more than a grave; it is womb and nursery as well. Homer was wrong when he thought of the ocean as an all-embracing flood on the disc of the world, but he was close to the truth when he called it the beginning and the end of everything. Its mighty reservoirs are both the source and the goal of the waters that breed turmoil on the land. Its currents have marshalled the procession of climates down the ages by shifting the radiated heat of the sun. Over its sheltering shoals a varied multitude of creatures have spawned untiringly through more than a

billion years. In many indirect ways the sea has played a part in the drama of earth, a part whose significance does not pale in comparison with that of any more obvious protagonist.

During much of the past the ocean did not placidly lie in its proper bed, content to influence from afar the affairs of the land. Again and again it rose over the parapets of the continental plateaus and stretched its great fingers into the depressions. Sediments laid down in these shallow seas were later consolidated into rocks which are now conspicuously displayed on every major land mass of the globe. Because at present all continents stand especially high, only Hudson Bay and the Baltic recall the waterways that were once so prevalent and so persistent. But even today the basins of the deep are full to the verge of flood. A very slight upwarping of their floors would set many a vagabond sea to wandering over the land.

One need but consider the broader outlines of geography to realize on what a tenuous thread hangs the dryness of the lands. If the rocks of the continents were smoothed to a common level, all lands would stand about twenty-three hundred feet above the sea. If the ocean basins were similarly planed, they would lie about thirteen thousand feet below the level of the sea. In other words there is a difference

of about three miles between the average height of continents and the average depth of ocean troughs. The difference between the highest mountain (Mt. Everest, 29,141 feet) and the deepest known hole in the sea (Swire Deep, 35,410 feet) is but little more than twelve miles.

Compared with the radius of the earth these major relief features of the surface are no more significant than the irregularities on an eggshell. Slight writhings in the body of the planet would squeeze broad seas upon the lands. Erosion alone, by reducing the continents to sea level and dumping the débris into the oceanic basins, would create a universal ocean two miles deep over the entire globe.

Relegated to less than one-third of the surface of the earth, engulfed by waters ever hungry and alert, the continents have somehow kept their heads in the air. Despite frequent invasions by shallow seas, they have maintained their essential integrity through all the vicissitudes of time. Gravity determinations reveal the secret of their success. Their rocks are somewhat lighter than the rocks beneath the oceans; like icebergs that stand a little higher than the water in which they float, the continents rise above the denser formations that surround them.

The scientific conquest of mystery is apt to be a slow and arduous campaign. Because so much of the

deep is beyond the range of measurement and experiment, many an unfathomed cave still harbors an enigma. Myths with scant basis other than the absence of any irrefutable disproof still batten in the murk. Most venerable and sturdy of these are the legends of foundered lands, which have won adherents in every age since Plato first told the story of Atlantis to the world at large.

Progress of maritime exploration played havoc with many imaginary islands, but the continent of Atlantis survived by the simple expedient of sinking before any articulate inhabitant of the modern world could see it. Belief in it lingers not only because it pleases the mystic, but because it helps explain the worldwide distribution of closely related land-dwelling creatures by supplying a bridge for intercontinental migrations. Although there are other ways to account for the dispersal of such obvious relatives as the Australian kangaroo and the American opossum, not a few persist in the belief that only a land connection like Atlantis or the more ancient Gondwanaland can suffice.

One of the quaint concomitants of advancing knowledge is the growth of assumptions that raise more problems than they explain. With the proved difference in density between continents and ocean basins, it is difficult to imagine how any ocean bottom

of continental size might once have been dry land. It is even more unlikely that any of the great land masses ever lay beneath the abyssal deep. The larger lands display no formations that even remotely suggest the sediments of the deep sea. Continental marine deposits are invariably the hardened muds, sands, and gravels of shallow waterways, and the fossils entombed in them are the remains of shallow-water organisms. Excepting the occasional appearance or disappearance of volcanic islands, belief in a complete interchange of land and sea bottom is not only without any directly supporting evidence, but it is contrary to the evidence that does exist. Although the matter is still debated, there is a growing conviction that the fundamental architecture of earth was established before the dawn of geologic history; that since then both continents and ocean basins have held to the broad outlines of the original plan.

II

With hunger destined never to be wholly appeased, the sea like a dogged monster persists in its attempt to swallow the lands. It may be seen today spilling over the shelf-like margins of the continents and clawing at the rocks beyond. Relentless and ceaseless is the surf along a million miles of shore,

and despite the ultimate futility of its striving, it is yet powerful among the despoilers of the land.

Three types of movement agitate the deep, and these are the source of all its power. Weakest of the trinity are the tides. These strange daily surrenders of the body of the sea to the persuasion of sun and moon have little effect upon the land excepting where narrow bays face the uprising of the water. In such an estuary as the Bay of Fundy the ocean flows and ebbs with the rush of a mighty river, each day rising and falling as much as thirty, forty, or even fifty feet in the narrow headward extensions of the inlet. Strong currents dragging sand and gravel scour the bottom and alter its configuration. Other currents are born of winds blowing obliquely against the shore, but their work is largely the rearrangement of débris produced by more vigorous forces. Among the movements of the sea, only the waves are of any great significance as sculptors of the shorelines.

Frequently on the bold coasts of the North Atlantic the sea and the land have come to grips. When a northeaster blows hard upon the granite headlands of Maine, waves beat the rocks with the incessant rhythm of a trip hammer. One by one they swell and break and sink into the welter of their spume. With the force of a battering ram they pound into the crevices of the cliffs, dislodging chunks which the

backwash carries away. Rugged though they are, not even the ramparts of Maine can withstand such attacks, repeated in an endless succession of storms. Slowly they crumble and retreat.

In England, whose pride is the mastery of the seas, the sea has ironically claimed some of its most spectacular victories. The soft chalk cliffs of Dover are even now receding at the rate of fifteen feet each year, and at Cherbourg across the British Channel, the fury of a single storm in 1836 tossed the three and a half ton blocks of a breakwater over the top of a twenty-foot wall. Long stretches of the Yorkshire coast have been worn back by the waves, some portions as much as two miles since the Roman occupation. Near Yarmouth on the North Sea the town of Dunwich was a considerable seaport in the eleventh century. By the sixteenth century it had been nearly devoured by the waves. Without discrimination they ingorged woodlands and meadows, houses and churches, town hall and jail. Cemeteries were laid open to the profanation of the birds. Today little but tradition remains of an ancient and thriving town, although a few modern descendants keep its name and memory alive.

The fate of Dunwich has been the fate of many other places, in England and elsewhere. Perhaps the most telling example of marine erosion within

historic times was the rapid and almost complete destruction of the island of Heligoland at the mouth of the Elbe in the North Sea. Relentlessly gnawing at the weak sandstone rocks, waves reduced the periphery of Heligoland from one hundred and twenty miles in 800 A.D. to forty-five miles in 1300 A.D. By 1649, the circumference had wasted to a meager eight miles, and by 1900, to three miles. Then, on the brink of extinction, the ill-fated island was rescued by man. Germany acquired it for a naval base, surrounded it with a powerful concrete wall, and halted the lethal depredations of the sea.

Countless tons of water endlessly surging on countless miles of shore keep the coastlines of the world in a state of continuous flux. Dynamometer readings near the island of Tyree on the Atlantic coast of Scotland have shown an average wave pressure of 611 pounds per square foot for summer, and 2,086 pounds for winter. Pressures as great as three tons to the square foot were recorded during heavy storms. No rock can forever withstand this power of the driven surf. By the sheer force of impact, by the explosion of compressed air when the water recedes from crevices in the headlands, and especially by the abrasive action of sand and pebbles, the waves tear down the land with a persistence that knows neither mercy nor respite.

Grinding along the base of a steep shore, the wind-tossed water cuts notches and caves until the overhanging rocks collapse. Like stretcher bearers the undertow and the longshore currents remove the fallen from the field of battle. Again and again the attack is repeated; foot by foot the cliff retreats. The coastline grows irregular as the waves make little bays in the weaker zones. Caves may eat into either side of a promontory until their meeting forms an arch. If the arch falls, an isolated stack of rock stands fast for a time with the sea frothing at its feet and the shore receding behind it. But there is no compromise with the fury of the deep; this too is fated to crumble into oblivion.

With retreat of a wave-cut cliff, a rocky platform just below the level of low tide is all that remains of the former land. Over such a bench, sand and gravel are constantly swept to and fro by the waves and the backwash, until eventually they are dropped in the deeper water at the outer edge. The terrace grows wider by continued erosion at the landward and continued deposition at the seaward side, until in time it may expand to a considerable plain. Great plains formed in this fashion and later uplifted by convulsions in the body of the earth may be seen in western Norway, northern Spain, and eastern India.

Ten to sixty miles in width, they are impressive monuments to the avarice of the waves.

Fortunately for the continents the earth is restless. Always before the victory of the sea was complete, writhings in the crust have raised the embattled coastlines and restored their stolen margins. High and dry on many lands are the varied toothmarks of the deep. Below, the dauntless ogre carries on, forever fretting and clutching at the rocks with the anguish of starvation.

III

No one can know how much land has already gone down into the stomach of the sea. The waves have been but one among several of its caterers. Indeed, of all the fodder consumed through the ages, the harvest of the waves represents but a meager fraction. Since the day when the first winds blew and the first rains fell, an army of erosive agencies has been stripping the continents and dumping the refuse in the ocean basins. Whatsoever instrument may pry a grain of rock from its moorings under the air, and howsoever long may be its journeying, it will probably achieve in the end the bourne of the deep, whence only a cataclysm may bestow a return.

In their movement from the highlands to the pro-

founder abysses of the sea, fragments of rock may linger for a time along the shores, reluctant as it were to accept fate's final decree. Within the limits of high and low tide, in a zone scarce half a mile wide at the widest but as long as the combined coastlines of the world, the particles are arranged by the toiling waters in a variety of deposits.

Currents prowling along the shores may filch the finer sediments and cache them in recesses in the lee of cliffs. Eventually the waves and the undertow mold such accumulations to crescent-shaped beaches. Although most beaches are made of sand, some can boast pebbles as broad as the palm of one's hand, ridged high and dry by storm-driven breakers. On gently sloping shores, along the line where waves first drag on the bottom and break, the so-called barrier beaches or offshore bars are built in the form of long narrow islands separated from the mainland by lagoons.

Endlessly the waves and the currents both build and destroy. Where a longshore current is forced into deeper water by an irregularity in the coast, it loses velocity and drops its load of sediment. Jutting sand spits result, and a host of related shoreline adornments that the water is forever remodeling. Characteristically fickle, the sea may carve out an island and then promptly reunite it with the main-

land, as in the famous example of the Rock of Gibraltar.

Indeed, the restless drive of nature is nowhere better illustrated than where the ocean meets the land. On the seashore everything is rapidly becoming something else. Bars may grow at the rate of two hundred feet a year, and then suddenly with a shift of current, disappear. Beaches may come and go within the span of a few decades. Landmarks of a lifetime perish with the storming of a night. And nowhere better recorded are the ceaseless warpings of the earth's crust which play such significant rôles in the evolution of nearly every coastline in the world.

Although abundantly destructive within his lesser sphere, man does not generally rise to the dignity of a geologic force. On one quaint occasion, however, he found himself playing god to a strip of shoreline on the Gulf coast of Texas. During a recent uplift of this coast, a series of offshore bars and lagoons had been built between the mainland and the Gulf of Mexico. There followed a slight submergence that flooded the lower ends of the rivers and enlarged the lagoons to such sizeable indentations as Galveston Bay. On the northwest side of this particular embayment is a large cove known as San Jacinto Bay, the site of man's unique adventure.

Goose Creek drains into San Jacinto Bay, and near its mouth in 1917 a rich oil field was opened. In the eight following years an estimated one hundred million barrels of oil, gas, water, and sand were brought to the surface. Scarcely one year had elapsed, however, before it was apparent that the removal of the subterranean material was causing the middle of the field to sink. Gradually the sea oozed in so that planked roadways had to be laid and derrick floors built higher. Vegetation on land that for a century had furnished good grazing for cattle shriveled and died as the salty water seeped in among the roots. Cracks opened in the streets of the little town of Pelley on the northern margin of the field. In some places the ground sank more than a foot, with earth tremors sufficient to break dishes in the houses. In the end nearly four square miles of land directly above the area of maximum extraction sank three feet beneath the sea.

What man has done on a modest scale in Texas, nature has done on a grand scale both there and elsewhere. Most of the shorelines of the world have been either rising or sinking throughout their history. A succession of recent uplifts has so altered the coast of southern California that wave-cut terraces may be seen there, rising in gigantic steps to as high as fifteen hundred feet above the present level of the sea.

Most of coastal Maine, on the other hand, has sunk so that its rivers have become estuaries, its hills islands and jutting headlands.

Shorelines, like rivers and men, tend to follow their appropriate pattern of change from infancy to senility. All newly submerged coasts are irregular because the differentiated topography of stream sculpture determines the outlines. Bays, promontories, and islands clearly bespeak the drowning of the land. Waves first attack the more exposed headlands, accentuating the initial irregularities of the coast by cutting cliffs where the rocks are strong, and coves where they are weak. Undertow removes the loosened detritus to the deep water beyond the breakers. With time, however, the débris accumulates sufficiently to fringe the promontories with embyro beaches. Longshore currents gradually curve the ends of the beaches into the bays, where they are built above sea level by the laving of the waves.

While currents are fashioning all sorts of deposits at the mouths of the bays, and waves are gnawing away the buttresses at their sides, rivers are building deltas at their heads. As the bays are thus reduced from both landward and seaward ends, the shoreline slowly straightens. When river sediment and vegetation have completely filled the bays, when bars and beaches have made a nearly unbroken

chain from headland to headland, the shoreline reaches its maturity. Thenceforth the cliffs recede in a nearly straight line, indented only where the waves wear back the softer rocks with exceptional rapidity. The bench at their feet grows wider until in old age the waves lose their power in friction as they struggle over its shoals. Quiet then comes to the shore until new writhings in the crust beget a new cycle of change.

Where uplift has made land of a portion of the sea bottom, the shore evolves through an entirely different series of changes. A flat and gently sloping plain flanks the coastline, and the waves break well out from the land. Near the line of breakers, offshore bars are soon erected above the level of high tide. Storms in time tear down the seaward faces of the bars and toss a portion of the débris over to the sides facing the lagoons. Galveston, Texas, which is built on such a bar, can testify to the occasional vigor of this process. The hurricane of 1900 drove a frenzied sea through her streets.

Erosion on the seaward and deposition on the landward side of the bars cause them to migrate slowly toward the mainland. Meanwhile, sediment slowly fills the lagoons and converts them into tidal marshes. Eventually both bars and filled lagoons are destroyed by the waves. Now in the maturity

of the cycle, the sea attacks the mainland without hindrance, recessing the cliffs and broadening the bench at their feet. With the further widening of the bench in old age, the cycle ends exactly as it does in the shoreline that has sunk.

IV

Seaward of the breakers, the submerged margins of the continents stand ready to receive the waste from the land. With width that averages seventy-five miles, but varies from five miles off southern California to more than three hundred miles off the Arctic coast of Siberia, these continental bibs usurp some ten million square miles of the earth's surface. Their slope is typically from six to ten feet to the mile, so gentle that if the water were to be removed they would appear as smooth and nearly level plains. At their outward edges, where the water averages six hundred, but varies from three hundred to twelve hundred feet in depth, they give way rather abruptly to the deep ocean basins.

The continental platforms are the no man's land where two worlds meet. It is there that the fury of erosion yields to the calm of deposition; where most of the sediments torn from the highlands are ultimately laid to rest. There through forgotten

ages forgotten dynasties of plants and animals have lived, without sinking to the degeneracy of the depths nor rising to the challenge of the heights. There, in a word, the vigor of the sunlit world blends with the somber quiet of the abyss.

Waves and currents wandering over the continental shelves spread the gravels in layers near the shore, and farther to seaward the lighter sands and muds. Under exceptional conditions, coarse gravel may be carried locally as far as ten miles to sea, whereas the finer sediments may nestle close to the shore. Deposits of this sort have accumulated on the continents whenever earth warpings have made lowlands that the sea could invade. Cemented and uplifted with time, they constitute the commonest of all rock types, and may be seen today even at the summits of lofty mountains. Stirred from slumber by the earth's unrest, they must suffer anew the tireless bombardments of the air.

Most interesting but least well understood among the habitués of the shallow water zone are the limy deposits of so many seas and ages. They all are clearly mothered by rivers bearing calcium carbonate in solution, but their paternal parents are various and frequently vague. Several agencies may reduce the amount of carbon dioxide gas dissolved in sea water, and when this happens where the water is

saturated with calcium carbonate, lime mud will drop to the bottom. Evaporation or a mere rise in temperature, even a severe storm, may drive some of the carbon dioxide into the air and cause precipitation of calcium carbonate. Certain bacteria may bring about a similar result by generating ammonia that combines with the carbon dioxide. Other plants by feeding on carbon dioxide bring other limy accumulations to the sea floor; and a variety of animals account for still more by building their skeletons of calcium carbonate and leaving them behind by the millions of tons when they die.

Some calcareous deposits seem exclusively the result of lifeless processes. Thus in the Mediterranean at the mouth of the Rhone, great quantities of sand have been cemented into rock by the superabundance of calcium carbonate brought to the sea by the river. Less clear is the origin of the fine white limy mud now accumulating over several thousand square miles of shoal water in the Bahama Islands. These sediments show no trace of organic structure although the water about them swarms with bacteria. Whether they are being deposited as a result of midsummer heating and evaporation of the sea, or because of ammonia liberated by the bacteria, is still a debated question.

There is no doubt, on the other hand, concerning

the organic origin of the limestone banks so common in the Gulf of Mexico and the Caribbean Sea. Here nature displays with vast prodigality the fertility of her womb. Shelled animals of every description and in countless numbers find existence easy amid the abundant warmth and the current-borne food of the shoals. But even the favored must some day die. Under the pulsing richness of the living carpets lie the stolid floors of the dead. Skeletons of lime-secreting molluscs, echinoderms, worms, corals, and seaweeds pile high on the banks, and are cemented into rock by the solution and redeposition of calcium carbonate. Throughout the rock record of the past are many formations of this nature, some of them made almost wholly of the calcareous carcasses of marine creatures.

Most widespread of all organic limestones are the coral reefs of southern seas. They sprawl over half a million square miles, and detritus worn from them covers perhaps an even greater area. During much of the past, when seas were more uniformly warm, corals flourished everywhere. Louisville, Kentucky, is built on a coral reef over three hundred million years old, and contemporaneous reefs throve within a dozen degrees of the north pole.

Because melting of the late continental ice caps cooled the seas of the northern hemisphere beyond

the tolerance of the coral polyp, living reefs occur today only in tropical and subtropical regions where the average temperature of ocean water is 68° F. or higher. Because corals also are sensitive to mud and fresh water, they are never found near the mouths of rivers or where waves disturb the finer sediments of the sea bed. Nor can they live for more than a few hours above the level of low tide or in water deeper than one hundred and fifty feet. Despite these restrictions they have built large reefs in many places. Well named, indeed, is the Great Barrier Reef that parallels the northeast coast of Australia, from ten to ninety miles wide, and more than one thousand miles long. Between it and the mainland lies a quiet lagoon some twenty to eighty miles broad. Deep enough throughout to permit the movement of ships, it is easily the finest harborage on earth.

When the young coral enters the world, it swims about as freely as a fish until it finds a suitable place to settle and to indulge the innate lethargy of its kind. There the larva grows into a bag of flesh with a fringe of tentacles around a cavernous mouth. It secretes from its bottom a limy platform to sit on, and sends out buds that grow into new polyps. In time a colony of corals develops much in the manner of a growing tree. Isolated colonies scattered over the sea floor are broken and ridged by waves

and currents. Continued growth of both corals and a host of other creatures that gather about the incipient reef eventually raises the mass to the level of low tide. At that point organic growth must stop, but the surf may continue to heap up fragments of rock until the reef lifts its head from the water.

When Darwin visited the South Pacific, he observed that some reefs hugged the shore like fringe, that others were separated from it by shallow lagoons, that still others made rings around water rather than land. He concluded that the latter two types had been built along the shores of sinking volcanic islands. Submergence, if not too rapid, might kill the corals on the inner margin of a fringing reef while allowing those on the seaward edge to grow upwards as rapidly as the island foundered. Partial disappearance of the land would thereby produce a barrier reef separated from shore by a lagoon. Complete disappearance would leave the reef as a circular atoll.

Knowledge has grown since Darwin proposed this theory to account for the abundance of reefs in water too deep for the delicate sensibilities of corals. On the whole the new facts support it. Other explanations have been advanced, but the subsidence theory remains the best.

V

Outwards, the varied activities of the shallows grow feeble with the deepening of the water to the verge of the abyss. Usually near a depth of six hundred feet, the bottom steepens to slopes that average 13° or 15°, but which may be as sheer as a mountainside. At about six thousand feet the declivities soften into plains of almost imperceptible inclination, which are at once the most extensive and the most striking feature of the ocean troughs. Neither currents nor the wildest storms can sow any tumult on these pastures; no ray can brighten their gloom or lessen their chill. Abandoned, they sleep through the night of geologic time.

So long as the laborious and costly use of the sounding lead remained the sole means of exploring this kingdom of the abyss, detailed knowledge of submarine geography was slow to accumulate. In a famous essay, Huxley described the basin of the North Atlantic, and at the same time expressed the nineteenth century view of ocean floors in general.

"It is a prodigious plain," he said, "one of the widest and most even plains in the world. If the sea were drained off, you might drive a waggon all the way from Valentia, on the west coast of Ireland, to Trinity Bay, in Newfoundland. And, except

upon one sharp incline about 200 miles from Valentia, I am not quite sure that it would even be necessary to put the skid on, so gentle are the ascents and descents upon that long route. From Valentia the road would lie downhill for about 200 miles to the point at which the bottom is now covered by 1,700 fathoms of sea-water. Then would come the central plain, more than a thousand miles wide, the inequalities of the surface of which would be hardly perceptible, though the depth of water upon it now varies from 10,000 to 15,000 feet; and there are places in which Mont Blanc might be sunk without showing its peak above water. Beyond this, the ascent on the American side commences, and gradually leads, for about 300 miles, to the Newfoundland shore."

The twentieth century that substituted hydraulic brakes for skids likewise replaced sounding leads with sonic depth finders. By measuring the time taken by a sound emitted from a ship to be echoed from the ocean bottom back to the ship, accurate and rapid calculation of any depth is now possible. Only soundings can limn the contours of the mysterious lands beneath the sea, and with the perfection of sonic sounding devices the science of oceanography is ready to mature. Although certain submarine regions as large as Mexico are still more vague than

Mars, the gateway to a fuller knowledge is open.

Already it is obvious that belief in the unmitigated monotony of the ocean floors was an exaggeration born of ignorance. It is true that the river-carved valleys which enmesh the lands like the veining of a leaf do not there exist; that no instrument of erosion can carve irregularities in rocks beneath the shield of the open sea. It is also true that the smoothing hand of deposition tends to blur the outlines of such relief features as do exist. Nevertheless, exploration during the last decade has illuminated a hitherto unsuspected variety of topographic contrasts in the hidden kingdoms of the main.

For some time men have known that the expressionless plains of the abyss were locally varied both by the peaks of volcanoes and by the valleys called deeps. Multiplication of soundings has multiplied the established number of these features until they are now recognized as conspicuous elements in the submarine scene. Not a few volcanoes rise high enough to form such islands as the Hawaiian Group, and many others just fail to reach the surface of the sea. With them are the long submerged ridges and the ranges born of buckling in the crust. For contrast, in over fifty downwarped portions of the bottom, the ocean is three miles deep or more. The

Japanese Islands rise abruptly from the trough of the Tuscarora Deep where twenty-eight thousand feet of water weighs upon the earth. East of the Philippines is a hole from whose floor Mt. Everest might rise and fail by a full mile to achieve the air.

When Captain Phipps made the first successful deep-sea sounding in 1773, he rubbed tallow on the lead and acquired a sample of blue mud that resembled nothing ever seen before. Thenceforth, improvement in bottom samplers kept pace with improvement in sounding apparatus. The light of a brighter knowledge is consequently beginning to reveal not only the geography of the lands beneath the sea, but also the nature of the strange blanket that covers them.

The finest products of continental erosion subside at last on the slopes that lead to the profounder depths, and accumulate there as muds of varying composition and color. Some consist chiefly of the pulverized shells of lime-secreting animals; others are almost entirely volcanic. Some are green from the sea-born mineral, glauconite; others are red from tropical clays abounding with oxidized iron. Most, however, are blue by virtue of organic matter that extracts the oxygen from the iron compounds.

Blue muds fringe nearly all the coast lines of the world in waters ranging from seven hundred

and fifty to more than twelve thousand feet in depth. By covering some fifteen million square miles, they monopolize an area one-fourth the size of all the continents combined. Last product of the turmoil of the land, they mark the frontier of a world that turmoil has never touched. For beyond them spreads the greatest and most silent cemetery on earth. Hordes of one-celled plants and animals swarm in the surface waters of the sea till life and buoyancy depart. Slowly then they sink like snowflakes to the abyss, where they have gathered through the ages to match the vastness of their mausoleum with the vastness of their numbers.

The limy shells of microscopic animals contribute largely to the fine-grained oozes that carpet some fifty million square miles of this valley of the dead. Below sixteen thousand feet, they are dissolved by the pressure and the increased amount of carbon dioxide in the water, but locally they are replaced by oozes rich in the more resistant tests of silica-secreting organisms. Over two million square miles of the Pacific and Indian Oceans, in places where the water is more than five miles deep, are underlain by a blanket of clay teeming with the glassy skeletons of one-celled animals. A belt of ooze rife with the ruin of glassy plants covers eleven million square miles of the Antarctic Ocean floor, and completely

girdles the earth. Denied any individual distinction in life, these tiny creatures gain in the aggregate an impressive immensity in death.

Speading far beyond the horizons of the organic oozes are the deposits of red clay that line the remoter recesses of the deep. Leagues from most of the outposts of continental deposition, they are mothered chiefly by volcanic dust either blown or floated to sea. A considerable part is meteoric, inheritance from the shattered worlds beyond our own. So slowly do the red clays accumulate that in a single haul from the South Pacific, the "Challenger" dredge came up with fifteen hundred teeth of certain extinct sharks. They had lain for no one knows how long an eon in an open grave.

And so in the vaults of the abyss the harassed children of sun and wind attain repose. There, too, the sea herself finds rest. Far from all forces of conflict, devoid at last of every hunger, her troubled heart is stilled by the slumber that knows no ending.

VII

The Wrath of Vulcan

SURCEASE from agitation is a boon but rarely bestowed on the children of earth. Born to turmoil in a murky past they have writhed in turmoil ever since, with seldom the blessing of a rest and never the hope of an end. There have been times, indeed, when the impatient forces of erosion have almost gained their goal, when wind and water and ice have almost leveled the surface of the globe. But ever like Sisyphus at the threshold of success, success has slipped from their eager hands. Ever before the last peak was blasted and the last hollow filled, the demons of the depths have risen to steal the fruits of their labor.

North of the northernmost tip of Sicily lies the belching island and mountain of Vulcano. Here, by ancient wisdom, was the portal of a nether world, where Vulcan kindled the fires of distemper in the bowels of earth. Nearby are other mountains of unhallowed fame, whose spasmodic vomiting of gas and rock has persisted for centuries unnumbered. From the dawn of civilization these hills of Vulcan and

others like them in many far corners of the globe have both charmed and terrified the human mind. Fearing their power, admiring their beauty, and pondering their mystery, men have been moved by volcanoes as by no other phenomenon of the physical world.

And no other phenomenon of the physical world has been more bedecked with myth and less with truth. Despite the shrewd guesses of Plato, Aristotle, and Strabo, and the observations of Pliny the Elder and his nephew, none of the early Greeks or Romans went far in explaining the nature of volcanic activity. Winds striking fire from subterranean seams of sulphur and coal was the fancy that most universally served as an explanation. Even as late as 1800, the followers of Abraham Gottlob Werner insisted that volcanoes arise from the combustion of coal seams. Only, indeed, within the last few decades, with the establishment of observatories in several lands, has knowledge of volcanic activity risen to the dignity of a science.

Fear and footless speculation retarded the development of vulcanology, although food for its growth was generously available. In addition to innumerable dormant and extinct volcanoes in many parts of the world, some four hundred and thirty active ones have contributed an approximate total of twenty-five

hundred eruptions within the span of human history. On a few very rare occasions, men have even been privileged to observe the delivery of a new volcano from the tortured loins of the earth.

Not far west of Naples, the ancient Lake Lucrinus had long lain placid in her bed. In 1536, however, she shivered with a strange unrest, and during the following two years the shivers increased in number and degree. On September 29, 1538, there opened an ominous crack on the shore of the nearby Bay of Naples. Water welled forth in a fountain until the crack enlarged to a gaping maw that glowed fiery red in the darkness. Two days and nights the fissure ejected great masses of stone and flakes of snow-white pumice until a conical hill had grown to a considerable size around it. The third day brought quiet and a flock of sightseers, many of whom paid for their curiosity with their lives when on the fourth day the eruption was renewed. On the eighth day the spasms subsided and have never since recurred. Monte Nuovo had grown in a week to a hill with a diameter of a mile and a half, and a height of four hundred and forty feet.

During the night of September 28, 1759, a new volcano was born in Mexico between the existing craters of Toluca and Colima, but on a plain some thirty-five miles away from the nearer of the two.

For three months the earth trembled and groaned until a fissure opened near a fertile hacienda known by the Indian name for paradise, Jorullo. Immediately a black cloud of steam and rock fragments took form above the vent. It broke with a flood of rain and mud which, in a few hours, covered the countryside with a blanket of subterranean débris. Mud, water, "ash", and earthquake for weeks made the little paradise a veritable hell. In less than two months, an eight hundred and twenty foot cone of fragmental rock had raised its head from the plain. Augmented by later eruptions, Jorullo today stands thirteen hundred feet above its base.

Fledgling volcanoes have been reported in several other regions, and it is interesting to observe that all of them entered the world in very similar ways. The birthplace is invariably in the neighborhood of existing volcanoes. Local temblors and underground rumblings proclaim the coming event. Fissures open and glow with a frightful incandescence; steam, dust, and larger fragments of rock are hurtled high in the air. Flows of lava seldom occur at the beginning of eruption, but they may come with the ebbing of youthful vigor.

The entire brunt of internal unrest is not inflicted on the land. Volcanic activity is at least as common if not as apparent beneath the sea. Many a mariner

has seen strange jets of steam, gas, stone, and even flame spurt high above the surface of the water. Pumice puffed full enough with gas to float has been known to mount from the deep and form a mantle over the ocean's breast.

In the troubled depths of the Mediterranean Sea, submarine eruptions have frequently occurred. Between Sicily and the African coast in 1831, Graham Island lifted its back like a whale in water that sounding had shown to be a hundred fathoms deep. It grew to a circumference of three miles and a height of two hundred feet, but was later reduced to a shoal by the pounding of the waves. There is evidence to prove that both Vesuvius and Etna began their hectic lives in similar fashion on the floor of the sea.

Near the active volcanoes of the Aleutian Archipelago in Bering Sea, islands are born with the whims of the nether gods. In 1796 an eruption threw up Old Bogoslof, which by 1823 had grown to an elevation of nearly half a mile. In 1883 New Bogoslof appeared, and in 1906 another eruption added a third island of considerable size between the original two. Unlovely Venuses breathing steam from innumerable craterlets, they rose in fury from the waves.

II

The earth, by such tokens as these, is still in the making despite the vicissitudes of two billion years. Not only have new volcanoes been born since the birth of man, but old ones have admirably displayed the execrable behavior expected of them. Yet these in all their ferocity are lambs beside the wolves of the remoter past, when the knighthood of subterranean viciousness attained to its finest flowering.

Had Noah sailed his ark during any of several of the remoter geologic ages, he would have made no landing on Ararat. For Ararat is not only a mountain of comparatively recent origin, but a volcanic vent of a pattern more fashionable today than yesterday. Indeed at those times when volcanic activity most profoundly altered the face of the earth, volcanic mountains were relatively rare. There were few eruptions of "ash" and lava around central points to produce such familiar cones as Vesuvius and Etna. The retching innards of the earth merely opened long cracks at the surface, and poured forth their lavas with undiscriminating abandon.

Just as some of the animals of Australia are anachronisms in the modern world, so are some of the volcanic activities of Iceland. The Laki eruption of 1783 was doubtless the greatest within human

history. After a prelude of earthquakes in a steady crescendo of violence, a torrent of lava rose out of the fissure of Skaptar Jökull. From the western end of the twenty mile gash it poured down the steep-walled defiles of the river Skaptâ, turning the water into hissing clouds of steam and spreading over the fields beyond the canyon walls. Moving relentlessly onward, the demon of destruction overwhelmed a lake and many square miles of lowland before it finally stiffened and lay still.

From the eastern end of the same fissure a similar flood of lava desolated the channel of the Hverfisfliod. For forty and twenty-eight miles respectively these two black flows of liquid rock reached forth like the fingers of death. Filling the gorges, hurling great stones in the air with the force of imprisoned steam, damming the mouths of tributaries to destroy the hamlets along their banks, they inundated more than two hundred square miles of the countryside with rock that exceeded the bulk of the loftiest mountain in Europe.

In all its dramatic fury, however, the Laki eruption was but the mellowed offspring of a greater fury that has raged from time to time in ages past. Beneath the recent flows of Iceland is a basement composed of much older and vaster flows. Almost the entire country, indeed, is built of lava born of

clefts in the crust of the earth. Not only Iceland, but portions of both East and West Greenland, the Faröe Islands, northern Ireland, and the Hebrides, have been cut from similar cloth. Lava flows varying in thickness from a few feet to more than a hundred, and massed to an average height of a few thousand feet, are responsible for some sixty thousand square miles of land in the North Atlantic. Presumably of the same origin is the submarine ridge that traverses the ocean floor from the Hebrides through Iceland to Greenland. From these facts geologists have inferred the existence of a lava plateau whose gargantuan hulk once sprawled over a million or more square miles, most of which has more lately foundered in the sea.

The traveler in northwestern United States need not resort to inference to know the stupendous importance of fissure flows in shaping the physiognomy of earth. Two hundred thousand square miles of Washington, Oregon, Idaho, and northern California are covered by lava that welled through cracks to the surface. Countless flows of no considerable thickness spread far and wide, piling up in places a full mile deep and smoothing the rugged Miocene landscape to a nearly featureless plain. The Columbia and Snake have since carved deep gorges in the great plateau without anywhere revealing such

cones and craters as constitute so striking a scenic feature of the region today. It is, accordingly, generally agreed that most of the lavas were vented through unadorned fissures; that the volcanic peaks of the Cascade Range represent an aftermath of relative insignificance.

Such mighty bleedings of the inner earth have left their mark on every continent. The Deccan Plateau of peninsular India is a mass of fissure flows that transgressed nearly a quarter of a million square miles, and multiplied to the prodigious thickness of ten thousand feet along the Bombay coast. Remnants of similar plateau lands occur in Argentina and Brazil, and in Basutoland, South Africa. These with their lesser brethren of various ages and places are monuments to what is easily the grandest phase of volcanic activity.

III

The business of monuments, unfortunately, is to commemorate but not to explain. Volcanic activity is an outward token of the inner forces that shape the globe, active forces that active volcanoes best elucidate. Fissure eruptions have all but disappeared from the modern world; only the cold dead lavas of the flows remain. Out of these the geologist

has pried not a few of the answers he seeks, but he has failed to discover all because dead rocks like dead men guard their secrets well.

Yet like life, which has survived for so many eons the death of so many dynasties of living creatures, vulcanism, too, has persisted to the present. When the lava of ancient fissures froze in death, the restlessness of the earth did not also die. Only its surface expression has changed with the years. There still exists a type of active volcano so reminiscent of the fissure volcanoes of departed ages that the geologist turns to it for the answers to his questions.

Especially does he turn to the Hawaiian Islands, for there at the crossroads of the Pacific where races have met and mingled, the older and the newer varieties of volcanic behavior seem to have met and mingled too. Although these islands are the peaks of a mighty mountain range, different in form from the planes produced by the more venerable flows, they are clearly the children of fissures. The lavas responsible for nearly their entire bulk are identical with the lavas of the ancient fissure flows. Where activity lingers in the Hawaiian craters it is an activity of a kind that is almost unique in the modern world, though presumably common enough in more than one epoch of the past.

Unlike most volcanoes of the world today, the

islands of the Hawaiian Group, despite their prodigious height, do not rise abruptly from their bases. Ranged in two parallel lines that doubtless mark the location of fissures beneath the ocean floor, they have been built towards the sky by the emission of countless flows of very fluid lava. Like honey the subterranean juices oozed for many miles before congealing into thin, nearly horizontal shields. When at last they achieved the air, they continued to multiply, erecting around the more active conduits of the fissures the colossal domes that constitute the several islands. Rising over two miles from the sea and over five miles from the ocean floor, they constitute the grandest assemblage of volcanic mountains anywhere on earth.

One island more than any other in this garden of volcanoes commands the attention, because it alone persists in its infernal flowering. Surmounting the vast pile of lava flows that have brought the island of Hawaii above the level of the ocean are five great dome-shaped vents. There are Mauna Kea and Kohala, mighty centers of eruption in bygone days; Hualalai, quiet since 1801; Mauna Loa and Kilauea, still stirred by the distempers of deep unrest.

Mauna Loa is the giant among living volcanoes, rising nearly fourteen thousand feet above the sea in a dome that represents but a small portion of its

total bulk. Its crater is over three miles wide and a thousand feet deep. When in eruption, fountains of white-hot liquid rock spurt hundreds of feet in the air; streams of lava, so hot and fluid that they may flow like streams of water for fifty miles before congealing, well out of cracks in the flanks.

The usual aspect of Mauna Loa, however, is not spectacular. Near its base the slope of its sides is a scant two degrees, and at no place greater than ten degrees. Professor Dana, who visited Hawaii in 1840, expressed an opinion that few would quarrel with today. "I was astonished," he wrote in a letter to a friend, "with the tameness of the lofty Mauna Loa. I have never seen a mountain one-third its height so utterly destitute of all sublimity or grandeur as this mountain appeared to us, walking along at its foot. It is an evenly rounded elevation, without one valley or gorge, one peak or ridge, to diversify its surface. I can compare its shape to nothing better than a saucer turned upside down."

Twenty miles down the slope of the dome of Mauna Loa, and nearly ten thousand feet lower than the crater, lies the caldron of Kilauea, most steadily active volcano of the modern world. Sunk within a ring of towering cliffs is a black expanse of lava, six square miles in extent, irregularly elliptical in shape, and frozen solid except for the circular vent

of Halemaumau, the House of Everlasting Fire. In this pit a lake of boiling lava endlessly seethes, its level rising at times to the top of the crater, and falling at other times from view. Feared by the natives for its ominous appearance and its occasional outbursts of explosive fury, Kilauea is yet esteemed by scientists for its usual good behavior and its amenableness to observation. It has been studied intermittently for more than a century and intensively for more than two decades, so that it easily stands as the most instructive volcano in the world today.

The studies of Kilauea have focused on the solution of three major problems: the source and movement of its molten lava; the origin and maintenance of its heat; and its relationship to the larger Mauna Loa on whose flank it festers like an ulcerous sore. It is now well established that the vent of Kilauea is not, as was formerly believed, the end of a narrow tube through which lava rises from a single flask-shaped reservoir of liquid rock below. After the explosion of 1924, when Halemaumau cleared its throat with surprising violence, the pit was exposed to a depth of fifteen hundred feet. Six hundred feet above the bottom a great spot each night glowed red. A smaller area on the floor also glowed, and roared with the escape of imprisoned gas. These places probably marked the outlets of feeding chan-

nels; but when the lava eventually returned, it spouted from a third feeder high on the opposite side of the hole. Such behavior suggests that Halemaumau is a collecting basin supplied by many small local chambers of lava which emit liquid rock of differing gas content, temperature, and pressure.

When the lava was thought to rise from a single deep-seated cavern, it was likewise thought to derive much of its heat from the physical and chemical activities of liberated gas. But with the discovery of the multiple source of the lava, gas-fluxing no longer seemed adequate. Furthermore, analysis has shown that the incombustible vapor of water constitutes four-fifths of the gaseous ingredients. Dr. T. A. Jaggar, director of the Volcano Observatory, has suggested that the chunks of solid but air-filled lava which continually break from the sides to sink in the molten swirl might bring enough oxygen to the deeper combustible gases to keep the furnace aglow. Whatsoever the cause, the furnace of Kilauea has kept aglow with remarkable fidelity these many decades. Doubtless it will continue to do so in the future without regard to the failure or the success of scientists in agreeing upon the reason.

Formerly it was generally thought that because the eruptions of Mauna Loa and Kilauea do not ordinarily occur simultaneously, the two must be in-

dependent of each other. More recently, however, Dr. Jaggar has tended towards a different view. Mauna Loa and Kilauea are located at the angles between the intersection of two vertical rifts in the crust of the globe. Because of the great weight of the volcanoes on the floor of the Pacific, gravity adjustments result in repeated movements of the earth blocks along the rifts, movements which could hardly affect one of the volcanoes without also affecting the other.

It is Dr. Jaggar's belief that periodically the volcanoes swell upwards by the lifting of the blocks between the converging fissures. Lava flows into the craters until its weight is sufficient to force the blocks back toward their original position. The lava then begins to subside and to flow from lateral fissures opened by the movement of the wedge-shaped blocks. Further subsidence of the lava ends the eruption. Many factors might cause the disparity in time and intensity of eruption in the two volcanoes, factors which, unfortunately, are still vague.

Not vague, however, is the impression that tourists receive from the activities in these Hawaiian craters. Few have witnessed at close range the booming eructations of remote Mauna Loa, but thousands have watched the ebullitions of more gentle Kilauea. When Professor Dana visited Hawaii in

1840, the activity of Kilauea had been reduced by a recent violent eruption. Only three pools in the great pot of Halemaumau were free of crusted lava. Dana's description, none the less, suggests as well as any the nature of a spectacle that must be seen to be appreciated.

"Fiery jets," he wrote, "were playing over the surface of the three lakes, but it was merely quiet boiling, for not a whisper was heard from the depths. And in harmony with the stillness of the scene white vapors rose in fleecy wreaths from the pools and numerous fissures, and collected over the large lava-lake into a broad canopy of clouds. . . . Occasionally a report like musketry came from the depths; then all was still again, except the stifled mutterings of the boiling lakes.

"In a night scene from the summit the large cauldron, in place of a bloody glare, now glowed with intense brilliancy, and the surface sparkled all over with shifting points of dazzling light like a 'network of lightning' occasioned by the jets in constant play, at the start of each the white light of the depths breaking through to the surface. A row of small basins on the southeast side of the lake were also jetting out their glowing lavas. The two smaller lakes tossed up their molten rock much like the larger, and occasionally there were sudden bursts to

a height of forty or fifty feet. The broad canopy of clouds above the pit, and the amphitheatre of rocks around the lower depths, were brightly illumined from the boiling lavas, while a lurid red tinged the more distant walls, and threw into ranging depths of blackness the many cavernous recesses."

Lurid and awesome though it is, such a picture hardly suggests the spectacle of Kilauea in a more exuberant mood, when hundreds of lava fountains rile the ruddy scum of Halemaumau, and the sky lights up with the glow of a conflagration. Nor does it suggest such calm as has fallen upon the fiery pit since its lake of lava leaked away through subterranean channels during the eruption of 1924. There is a rhythm to all things in nature, a systole and a diastole in the beating of every heart. The present lassitude of Kilauea will some day yield to vigor as it has yielded many times before—almost as surely as the sun that sets tonight will rise tomorrow.

IV

Volcanoes are personalities that resist classification. Although no two of them are exactly alike, they can nevertheless be broadly divided into two groups that differ fundamentally from each other.

In the first group are the ancient fissure vents and the volcanoes of Hawaii and Iceland, whose lavas are dark in color because they are rich in iron and poor in silica. Such lavas melt at relatively low temperatures, flow freely and for long distances before congealing, and lose their gases with a minimum of explosive disturbance. The result is relatively gentle eruption, with the building of low lava domes—or no domes at all—around the vents.

Far more spectacular are the volcanoes of the second group, whose lavas are light in color because they are rich in silica and poor in iron. Such lavas melt at relatively high temperatures, flow only short distances before congealing, and lose their gases with maximum violence. The result is relatively explosive eruption, with the building of steep-sided cones from lavas that sometimes flow and "cinders" that invariably are blown from the vents.

North of Sicily in the Eolian Isles the cone of Stromboli stabs the sky. Crowned with a diadem of glistening steam, it is visible by day through a radius of a hundred miles. By night it is equally conspicuous because of the mild explosions that rhythmically flood the crater with an eery light. Three or more times each hour since the dawn of the Christian Era, this "Lighthouse of the Mediterranean" has faithfully flashed its warning to wanderers over the sea.

On close approach the crater is seen to be situated on the side instead of the summit. Inside is a surface of lightly frozen rock, cracked and hissing with angry vapors. Here and there are pools of writhing lava, some puffing out steam like a locomotive, others quietly or violently boiling as their tempers dictate. Occasionally from one of them a large bubble of steam escapes with enough vigor to blow the lava scum into the air, and to brighten the cloud cap overhead. Quickly the fragments freeze and rattle down the outer slopes to the sea. The molten lava in the pool subsides until more steam accumulates and another explosion occurs. Thus at intervals measured in minutes Stromboli has for centuries spat out its spleen. Although the monotony of its rhythm has been interrupted at times by explosions of great intensity, it has fumed down the ages without achieving either peace or a decisive eruption.

The cycle of activity in the vent of this volcano follows a pattern that is fundamentally the same in all volcanoes of the explosive type. So long as convectional currents stir the stony porridge and relieve the pressure of rising gas, there is no eruption. Because of the narrowness of the chimney and the stiffness of the relatively cool siliceous lavas, however, convection is impeded. Steam periodically accumulates in scattered bubbles that coalesce, rise,

expand, and break with violence from the mouth of the vent—carrying with it the liquid and semi-liquid lava that lies athwart its path.

Generally, the longer a volcano rests between eruptions, the more violent will be the release of pent up gas. Vulcano in the Tyrrhenian Sea is a neighbor of Stromboli whose fretting is less frequent but far more emphatic. Recorded in its body is a complex history of vigorous activity and deathlike calm. The present shape of its cone was acquired in 1786, when for fifteen days a fountain of steam threw up an enormous quantity of "ash" and "cinders". Then for a century Vulcano lay quietly smoking. In 1888, after two mild eruptions in 1873 and 1886, violent explosions began to boom in the crater. At intervals of less than half an hour, steam and rock were blown into the air with ever increasing intensity. Projectiles of lava, some of them many inches in diameter, littered the ground within a radius of more than a mile. With a roar that was heard for miles around, the disturbance continued through several months. Finally, as all things must, the eruption ended and peace came down to the troubled land.

On the shore of the Bay of Naples the famed Vesuvius exhibits the traits of both Stromboli and Vulcano. Playing dead for a thousand years, fret-

ting in undertones for a century, or blowing the top of its cone to bits in the paroxysm of a week, Vesuvius is the moodiest volcano in the world. Those Romans who suspected its nature considered it extinct when, with consummate treachery in 79 A.D., it buried the towns of Herculaneum and Pompeii under a deluge of "cinders" and dust.

Since then the volcano has lain for the most part dormant, growling fitfully in its sleep, but rising now and again to hurl destruction over the land. During the last great eruption in 1906, it vented in a three-phased cycle first lava, then gas, then "ash". The gas blast was one of the most spectacular displays the eyes of men have even seen. With the roar of Niagara and the speed of a rocket, Vesuvius "blew off" like a locomotive for hours without abatement. So great was the pressure that the jet rose eight miles above the earth before it spread to the cauliflower cloud so characteristic of all eruptions.

Volcanoes like men grow old, and with the years their irritability may increase. Some of the grandest eruptions in the memory of man have occurred in aging volcanoes that have long lain still, quietly gathering strength for one last supreme protestation against the fate that not even volcanoes may escape. Such, it would seem, was the eruption of Krakatoa in the Dutch East Indies which, with little warning

in 1883, blew more than four cubic miles of its cone to bits. The detonations were heard two thousand miles away; the convulsions in the sea drowned tens of thousands of people on neighboring islands; dust shot high in the air encircled the globe. Such, too, was the eruption of Katmai on the Alaska Peninsula, whose unheralded explosion in 1912 plunged the countryside for a hundred miles around into hideous night, and buried it beneath five cubic miles of "cinders". And such was the beheading of Bandai-san in Japan, whose summit and side were blown out of existence in a scant two hours after resting in peace for a thousand years. A Japanese priest, presumably living by special dispensation on the favored side of the cone, survived to describe the wonders he had seen.

Two of the strangest and most terrible eruptions known to man occurred almost simultaneously on neighboring islands in the Caribbean Sea. Quiet since 1812, La Soufrière of St. Vincent Island began to stir during February, 1901. Quakes of increasing severity rocked the earth until spring of the following year. Then suddenly on the eighth of May, after a succession of tremendous explosions within the cone, a black cloud loaded with red hot dust surged from the crater and swept down the valleys to the sea. Although it spent its fierceness before

reaching the more populous regions, fourteen hundred dead men lay in its wake.

Nearby on Martinique, Mont Pelée had been at peace since 1857. After a prelude of earthquakes, rumblings, and the ejection of steam, the volcano erupted with a blast of red hot vapor very similar to that which had desolated St. Vincent just the day before. Anderson and Flett describe the catastrophe that destroyed in a flash both the city of St. Pierre and nearly all of its thirty thousand inhabitants.

"So deadly was the blast that swept the city, so awful in its completeness the destruction that it wrought, that few survived who saw the great black cloud descending from the mountain, but of those few there are some who have placed on record what they saw, and it is clear from their descriptions that in Martinique there was a repetition of what had happened in St. Vincent on the previous afternoon. The mountain burst open and a great cloud appeared near its summit. It arose with a loud, growling noise, and some say that in it they saw a bright red glare. Like an avalanche it poured upon the city, covering the distance in a few minutes, and enveloping all in total darkness. It passed almost as rapidly as it had come, and when the darkness lifted a little, it was seen from the ships lying in the harbour that the city was razed, and fierce fires had broken out in

many places. The north end of the town was practically wiped out in an instant; nothing was left but blazing ruins, the inhabitants perished where they stood. But in the south end the devastation was not so complete, the walls were left standing in many of the houses, and the living occupants rushed into the streets, yelling with pain and terror, terribly injured, throwing themselves into the sea to mitigate the agony of their burns. . . ."

V

Thus the earth in varied fashion submits to the storms that rage within her. Though men must sometimes pay with their lives for the joy of riding through space on her back, they ride for the most part in safety. They may observe at their leisure the wonder of her ways, and search for meanings more wonderful still. And of all the forms in the kaleidoscope of history, few are more fascinating than volcanic activity, few more revealing of the mysterious forces that have guided through two billion years the destiny of a world.

These forces, however, are so far entrenched that their surface expression can scarcely suggest the fulness of their might. Volcanoes at most are but passing pimples on the skin that betoken a deeper and

more dire distress. Since those distant days when the earth was young, hot magmas of liquid rock and gas have bred in her troubled body, and have struggled for outlet at the surface. Relatively few of these streams of subterranean infection, however, have reached their goal. Many have congealed within the outer shell of the globe where the erosion of a later day has bitten deeply enough to bare them. Innocent in death though they are, they tell of tempests that have raged with a fierceness that dwarfs all other storming.

In many regions, dikes of liquid rock have been shot like bolts from below to freeze in the fissures of the outer crust. Opened to view by the forces that distort and gnaw at the surface, they are ubiquitous reminders of the unrest that surges within. In many other regions, comparable intrusions have pried open the seams of horizontally bedded formations to insinuate themselves between the layers for many miles before congealing. The Palisades of the Hudson River have been cut from such a sill which had grown in places to the thickness of more than eight hundred feet.

In several areas, masses of stiffening igneous rock have bulged the intruded formations into domes. Stripped and dissected by the weather, the cores of these domes stand out like gigantic mushrooms of

stone, some of them a full mile thick and several miles across. One on the northwest shore of Lake Superior is estimated to contain some fifty thousand cubic miles of once liquid rock, a fitting monument to the enormous power that pushed it toward the surface. Yet even this is a babe when compared with the mighty batholiths that have squeezed and perhaps eaten their way from the depths to become major structural units in the architecture of the upper crust. Along the shores of British Columbia and Alaska, the Coast Range batholith stretches for more than a thousand miles, the greatest by far of all visible rock formations.

The origin and rise of these underworld materials, and of those that attain to the surface through the throats of volcanoes, constitute one of the profound problems of modern science. Its solution would eliminate some of the most stubborn mysteries on earth. Fortunately for the geologist whose pleasure is more in the pursuit than in the attainment of his goal, the problem is far from solved. And because its roots are in a region beyond the direct observation of man, it may never be solved. Yet knowledge somehow advances despite the narrowness of the path it must follow and the obstacles in its way. The ultimate explanation of vulcanism lies in

a cave that men will never see, but the mind may succeed even where the eye must fail.

Certain fogs, indeed, are already clearing. Scientists argue about the heat that stokes the furnaces of vulcanism. Some hold it a residuum from a globe that once was molten and is not yet wholly chilled. Others believe it the result of contraction and compression through gravity. Still others maintain that it is the offspring of radioactive change. All must agree, however, that it exists; that it seems to increase with depth until at the center of the earth it may mount well beyond the prodigious height of 100,000° on the Fahrenheit scale. Even at shallow depths the rocks are so hot that any cracking or buckling of the crust destroys their rigidity by reducing the pressure upon them. Liquid magmas eager with gas rush to the exits thus unbarred.

Much mooted are the problems of the mechanics whereby these materials ascend toward the surface, but one fact of great significance stands forth. The outer shell of the earth is cracked into mighty blocks that have shifted their positions from time to time. Their margins are zones of weakness, spawning beds of volcanic activity and sites of the major volcanic chains of the globe. Inescapable is the inference that the movement of these segments is the outstanding cause of the rise of liquid rock. The forces that

produce these movements are greater than any other force on earth. If ever they are completely understood, the baffling problems of vulcanism and many another enigma of the hidden realm will melt like mist in the sunshine.

VIII

A World in the Making

IT was the last night of August, 1886, and not quite ten o'clock. The good folk of Charleston, South Carolina were preparing for whatever rest the sultry stillness of the evening might bestow. Suddenly without warning or precedent, there rose in the darkness a roaring that seemed to fill both earth and sky. Dr. Parker, abroad on Tradd Street, thought a cyclone was howling down James Island Cut. Workers on the second floor of the News and Courier building thought a safe had been rolled over the floor of the office below. More quickly than any possible telling, the ground began to quiver, windows rattled, and people instinctively knew that an earthquake was striking the town.

Rapidly the intensity of the tremors waxed until it seemed that nothing might stand against them. Billows like waves at sea churned through the ground. Floors heaved, walls swayed, stone and mortar crashed down into the streets. Then in a trice the convulsion passed. Gas jets feebly flickered in a fog of dust whence rose the groans of the in-

jured, the shrieks of the hysterical, and the prayers of the pious to a god who did not understand.

A half century has passed since that evil night, and Charleston has all but forgotten it. Yet in that half century Thor and his hammer have not been idle. Three times has Japan alone been shattered by the blows and razed by the fires that almost invariably follow them. In 1891 and 1896, the toll in human lives was close to forty thousand. In 1923, more than a hundred and forty thousand were killed, nearly as many were injured, and billions of dollars in property were destroyed when Tokyo and Yokohama were shaken like mice in the jaws of their age-old foe.

Three times too has earthquake spread ruin in California since the Charleston disaster of fifty years ago. Stalking down the coast like a hungry cat, it sprang upon San Francisco in 1906, Santa Barbara in 1925, and Long Beach in 1933. The deadliest quake in the history of Europe laid low the city of Messina in 1908 and claimed the lives of more than a hundred thousand. Within the same brief span of years the demon fell upon India, South America, the West Indies, and China, with terrible destruction of life and property.

Although such disasters have been all too frequent, they record but a few of the shocks that have

racked the globe in fifty years. Many earthquakes are happily lost beneath the sea; many others, like the Montana quake of 1925, though severe enough to wreck great cities are centered in areas of sparse population. And many another is so slight that only the delicate seismograph can detect it. Yet so marked is the earth's infirmity, so false the concept of *terra firma*, that a perceptible trembling of the ground is felt at some place on the globe during every hour of the day and night.

There is ample proof that this tremulous condition is nothing very new under the sun. A full recounting of the quakes that have written themselves into human history would make a chronicle both horrible and monotonous. During the past ten centuries in China alone, over a million and a half persons have died violent deaths in earthquakes. In 1842, Mallet published a catalogue of the disastrous shocks recorded in human documents since earliest times. Two hundred and sixteen out of a total of 6831 were great enough to reduce whole towns to ruin. Many other catastrophes of similar nature must have occurred in days when the toll was not measured and recorded. In four thousand years, according to Mallet, some thirteen million people have been sacrificed on the seismic altar.

Earthquakes, by such tokens as these, take their

place in the vanguard of the enemies of man. With fire, landslide, and "tidal wave" as henchmen, they are a mightier menace than any other force in nature. Tornado, flood, and volcano are all but impotent in comparison.

Even sophistry, that lusty flower of the wishful ego, must wither when the earthquake strikes. Those who have made it their business to justify the ways of God to man have not been wholly successful in dealing with the symptoms of terrestrial distemper. Though excellent as expressions of wrath in a vengeful god, earthquakes are strange manifestations of grace in a god of alleged benignity. There has always been disagreement among the experts on the theology of disaster. Those who have interpreted earthquakes as rebukes of a stern but righteous deity have not always agreed as to who was being rebuked. When the great quake of 1755 destroyed Lisbon and sixty thousand of her inhabitants, the English clergy were certain that God was punishing the people for the spread of Catholicism among them. The Catholics, on the other hand, knew that the presence of non-Catholics had caused the calamity. Being in the majority, the Catholics allegedly ended the debate and appeased the divine indignation by the simple expedient of driving all heretics to the baptismal font.

Alas for the two-legged mammals in whose heads such wondrous fancies breed. They must endure not only the slings of the same outrageous fortune that harass the humbler legions in the army of life, but they must suffer the offspring of their own delusions as well. They may see what eyes have never seen before, but they are generally blind to the nature of the forces that swirl about them. They cannot perceive that the gods of earth have been building a world these past two billion years, oblivious to the squealing of mice and men.

II

So it is that although earthquakes have always commanded the attention of men, their significance in the economy of nature has been slow in dawning on the human mind. They have always inspired more terror than thought, more assumptions than reasoned conclusions. The speculations of the educated have been almost as sterile as the superstitions of the ignorant. Long before the birth of Christ, earthquakes stirred the imagination of philosophers. Anaxagoras thought them the result of ether rushing into subterranean caverns. Democritus maintained that heavy rains caused them by rupturing the ground. Anaximenes believed that the drying rather

than the bloating of the earth produced them. Aristotle held that a mingling of "moist" and "dry" made winds whose mad cavorting underground was reflected at the surface in earthquake and volcanic eruption.

Such concepts were only the initial spatterings of a rain of speculation that has muddied the minds of men throughout the ages. Fear and fancy easily ruled where reason could not reach. Only during the last few decades has a handful of men begun to fathom the mystery of earthquakes. With an ingenuity that has never been surpassed, they have blazed a trail of inductive thought into the very recesses of the nether world, and have founded a science of seismology.

At the base of this rapidly enlarging science is the rock of a simple observation: that earthquakes are vibrations in the stony shell of the globe. Further observations have taught that vibrations may be set in motion in different ways. They may be caused by the friction of one body moving against another, as when the bow is rubbed on the strings of a violin. They may result from a sharp blow, as when a bell is struck or a drum is beaten. They may follow the snapping of a solid substance that has been under tension, as when the ice of a river cracks and trembles with the breakup of spring.

In the speculations of the ancients, the vibrations

of the earthquake were generally attributed to friction or the jar of a sudden blow. Although faith in the friction of frenzied subterranean winds has been killed by the knowledge that no such winds exist, the jar of a sudden blow is still invoked as a cause of earthquakes. Lucretius was the first to argue that the fall of rocks from the roofs of caverns might result in widespread trembling of the ground, and champions of his view were legion as recently as a century ago. Today it is clear that although a local shock may originate in this fashion, the energy developed by falling rocks is far from sufficient to produce the far ranging disturbance of even a moderate quake.

Volcanic activity as a cause of earthquakes has always appealed to the popular fancy, and indeed it is true that the two have been closely related on many occasions. Even when no eruption occurs at the surface, the subterranean shifting of liquid rock in volcanic regions is a common source of shock in the solid earth above. These tremors, however, are seldom severe, and they never venture far from the places they were born. Frequently greater quakes keep company with volcanoes, not as mother and son but as sister and brother, children of the same weakness in the crust of the globe.

Neither friction nor a jar can account for such

a temblor as that which rocked nearly two million square miles of India in 1897. Although more severe than most, this earthquake was not unique. Like nearly all others it resulted from a chronic condition of stress in the earth. Since days that are lost in a misty past, the interior of the globe has been haunted by mysterious forces whose periodic release distorts the rocks of the outer crust. Bending slowly until their strength can no longer resist the strain, they give way along fractures with the suddenness of a sprung trap. Their elastic rebound to positions of greater ease sends forth the vibrations that are felt as earthquakes.

Although an overwhelming majority of quakes result from the abrupt displacement of rocks along such fractures or faults, the nature of the movement is variable. Some earthquakes herald the appearance of presumably newborn faults; others report the unrest in more venerable zones of weakness. Many deep displacements shock without breaking the ground above; many others produce escarpments that reveal both the amount and the direction of movement.

A hundred miles northwest of San Francisco, from Point Arena on the Pacific shore, one of the greatest fractures in the crust of the earth may be followed southeastwardly six hundred miles. Con-

spicuously marked at the surface by a belt of ruptured rocks along a depression, oblivious of hill and dale, the mighty San Andreas fault goes its determined way. On April 18, 1906, California was shaken to the roots by the horizontal slippage of great blocks of rock along this line of fracture. The land to the west of the rift sprang north with reference to the land on the east, in one place as much as twenty-one feet. For nearly three hundred miles, water pipes, roads, and fences were severed where they crossed the trace of the fault zone. San Francisco, nestling too close, tumbled and burned.

Behind Yakutat Bay on the southeastern coast of Alaska, the monstrous massif of the St. Elias Range rises some three and a half miles above the sea. In September, 1899, fresh spasms of growth in the colossus made the surrounding country quiver in a series of violent earthquakes. Glaciers were shaken and cracked, waterfalls were born to previously smooth-running streams, the configuration of the coast was profoundly changed. Beaches were lifted as high as forty-seven feet above the water by vertical displacement of the rocks along the faulted zones.

Such quake-breeding fractures engirdle the earth in two rather well defined belts: the one bordering the Pacific Ocean; and the other circling in a general

east-west direction through the Mediterranean, the Himalayas, and the East Indies. These belts mark the positions of most active change in the crust of the globe. The volcanoes and earthquakes that abound there are merely the sparks and vibrations from hammers that are building a world.

III

Earthquakes fade to insignificance when compared with the monstrous writhings of the crust which have marked the major events of two billion years. Though doubtless the cumulative effect of lesser spasms endlessly repeated, these world-molding distortions appear in retrospect to have moved with ponderous deliberation. Tirelessly they have wrought their mighty change in every age. By warping, tilting, and crumpling the rocks, they have thwarted erosion in its attempt to level the lands. Repeatedly they have allowed the seas to trespass upon the continents, and repeatedly have driven them home again. Ever, indeed, has the entire earth been putty in their hands.

And even today, after so many restless eons, restlessness persists. Under the seeming quiet of the most peaceful landscape, turmoil slowly festers. Where the continents give way to the sea, there is

abundant evidence of recent change in the elevation of many a land. The sea, with all its spuming, is the most stable feature on the face of earth. Although the level of its surface is somewhat higher along lofty than low-lying shores, the variation is insignificant. Although its volume has changed with the waxing and waning of glaciation, and its shape with the alteration of the floor, such changes are gradual and their effects along the shoreline uniform. Sea level is consequently an excellent surface of reference for the relatively rapid and variable movements of the strand.

There are many coasts, like the eastern coast of England, where waves are eroding so rapidly that the sites of still remembered farms and villages are deep beneath the waters of the sea. There are others, like the headward end of the Adriatic, where deposition of sand and mud has proceeded so rapidly that towns which once were seaports are now as much as twenty miles from shore. Striking though they are, such alterations of the coastline are but skin deep. They are not causally related to the equally striking and farther reaching changes that stem from a deeper unrest in the body of the globe.

Long stretches of coastline in many parts of the world are being warped by movements which are here in an upward and there in a downward direction

with reference to the datum level of the sea. It is clear in the record of the rocks that similar movements have afflicted the earth since earliest days. It is probable that inland and coastal areas have been and still are equally affected, although no precise method of measuring the movement of the former has yet been devised.

Many examples of recent elevation of coastal lands strike the eye that is prepared to see. Throughout the East Indian Archipelago, coral reefs, which not so long ago in a geologic sense were in the ocean, are now perched high and dry along the shores. The Italian island of Palmarola has risen more than two hundred feet since it was mapped in 1822. The upper part of the Scandinavian Peninsula has been gradually rising for several thousand years, in some places as much as three feet in a century. Strand lines with beaches, and wave-cut caves and terraces, have been hoisted a thousand feet above the sea in northern Sweden. Uplifted strands preserved in rare perfection line the edges of Scotland, Chile, and California.

Sunken coastlines do not as readily reveal their nature to the traveler's eye. The evidence of depression, though conclusive, may lie wholly beneath the water. On the north shore of Egypt, for example, several ancient tombs that were built on the land are

now entirely submerged. Similarly, the ruin of forests discovered off the coasts of Germany and Holland bears witness to the sinking of the shore. Soundings show that the trench of the Hudson River continues for more than a hundred miles beyond the harbor of New York City. Since rivers cannot cut their valleys beneath the ocean, the submarine channel traverses a region that must once have been dry land. The coast of Maine with its rocky islands and drowned rivers is more obviously a surface of subaerial erosion that has settled into the sea.

These movements that warp the shell of the globe are not always uniformly upward or downward in any given region. Point Fermin on the coast of southern California, and San Clemente Island fifty miles offshore, clearly show that they have risen from the water. Both display wave-cut terraces high above their present shorelines, so perfectly preserved that they must have been elevated in very recent times. The latter is gouged by the steep-walled canyons that record the youthful stage in the cycle of river erosion, an added proof of its comparatively recent exposure to the air. Midway and in a direct line between the two is the island of Santa Catalina, totally devoid of elevated terraces and deeply furrowed by the valleys of maturity. Evidence along the strand line proves that while her neighbors on

either side have been rising, Catalina has been foundering beneath the waves.

Not far from Naples on the shore of the Bay of Baiae, the remains of the temple of Jupiter Serapis may still be seen. Built by the Romans in the second or third century after Christ, it began to sink while yet in use. When the waves crept in to lave its marble columns, a second floor was built some eighteen inches above the original one. At a later and unknown date the court was buried twelve feet deep by a deluge of volcanic "ash". The ground continued to sink, and did not rest until the water had climbed nine feet above the blanket of "ash". Rock-boring molluscs, whose offspring still swarm in the bay, then drilled their homes in the columns between the top of the protecting "ash" bed and the surface of the sea. Other marine creatures left their shells in the sediments of the plain on which the temple stands.

After a long pause during which the borers thoroughly riddled the exposed portions of the columns, the land began to rise. Nobody knows just when the upwarp started, but documents of the fifteenth century show that the people of that day were aware of it. By 1741, when the building was excavated, the original floor had emerged from the water. Since then the unhappy structure has again begun to sink,

but much of what remains of it may yet be seen. Three of its columns still stand, each with the nine-foot girdle of perforations that tell of its sojourn undersea. Thus by a felicitous conjunction of archeological, historical, and geological evidence, these ancient stones record the earth's unrest.

Writhings such as these, though frequently downward with reference to the surface of the sea, have been on the whole in the opposite direction. The average height of the lands today is close to twenty-three hundred feet. The average depth of the ocean troughs is fully five times as much. Were the two ever smoothed to a common level, a waste of water two miles deep would swamp the entire globe. Long have erosion and depressive earth movements been working to achieve this goal, but without success. Again and again have the seas stretched covetous fingers over the lands. Again and again have they been repulsed by upheavals which have preserved the integrity of the continents through all the vicissitudes of time.

IV

Every acre of land in the world has suffered some kind of distortion at some epoch of its history. Certain areas have been obviously more affected than

others, and it is these that the geologist examines most carefully for the causes and the methods of crustal convulsion. In belts where rocks have been cracked and wrinkled and elevated—in the great mountain ranges of the earth—he ponders earth's greatest enigmas.

He breaks a shell from a peak ten thousand feet above the sea. The shell is clearly the skeleton of a marine animal, the rock a piece of hardened mud. He asks how the ocean floor of yesterday became the upland of today, and he searches the mountains for an answer. Although he has not yet found it, he at least has discovered the magnitude of the problem, and a multitude of clues that may ultimately lead to its solution.

Some mountains, like the San Francisco peaks near Flagstaff, Arizona, are wholly volcanic in origin. Others, like the Catskills, are remnants of high plateaus whose flat and undisturbed formations have been deeply chiseled by the instruments of erosion. Such mountains may attract the eye with the splendor of their mien, but they do not attract the geologist who seeks more significant symptoms of the earth's unrest. Rather does he obtain the evidence he requires from such a range as the Sierra Nevada, whose structure and elevation have been largely produced by faulting; from such a massif as the Black Hills,

carved from a mighty bulge in the crust; from such mountains as the Jura of Switzerland, where the rocks have been thrown into a series of wrinkles. And in the major mountain belts of the globe—in the Alps, the Himalayas, the Rockies, and similar chains—he finds the complex jumbles of both faulted and folded formations that testify to the earth's severest suffering.

Though the nature of the cataclysms that ravished these regions is vague, certain facts are clear. The rocks involved are typically and predominantly the hardened sediments of ancient seaways, heaped to the astounding thickness of several miles. More than thirty thousand feet of such formations are exposed in the Wasatch Mountains, yet this is but little more than half the thickness of comparable formations in the Alps. Along the axis of the Appalachians the strata are over twenty-five thousand feet thick, thinning not far to the west to less than half that amount. It is highly significant that not only in the Appalachians, but in all the other complex chains of folded mountains on earth, mighty accumulations of sedimentary rocks are held to long and relatively narrow zones.

Not less significant is the fact that the upheaval of such masses of rock has invariably been attended by considerable shortening of the circumference of

the globe. Sediments that had been deposited horizontally were mashed together by tremendous compressive forces when the mountains were built. Measurements show that buckling and shearing of the rocks at the birth of the Appalachians shortened the crust a hundred miles or more. Similarly, if the contorted strata of the Alps could be unscrambled and restored to their original positions, they would spread in places over areas nearly two hundred miles wider than the belt now occupied by the mountains.

Any theory that pretends to explain the origin of these major features of earth must first account for the gathering of sediments to excessive depths in limited areas. The predominating rocks of a typical mountain range are obviously similar to the gravels, sands, and muds that are being laid down today near the margins of the ocean. They are cracked by the sun where the periodic retreat of the tide bared their successive layers to the air. They are rippled by the waves that laved their landward edges. In them are the remains of animals comparable with those that haunt the shoals in modern seas. Accordingly, most geologists are agreed that the cradle of the typical mountain range must have been a shallow basin near the margin of a land mass that was suffering intensive and prolonged erosion. Today, along the eastern coast of Asia, great rivers are

pouring sediments into a series of such bays lying between the mainland and a festooned chain of islands. History, which has so often repeated itself in Asia, may be doing so again.

Sediments dumped into a shallow and narrow trough would quickly fill it if the trough were stable. To account for the tremendous thickness of shoal-water formations in the ranges, an adequate theory of mountain building must assume that the mothering troughs subsided as rapidly as the layers of sediment piled in. To account for the variability in extent and arrangement of the deposits, it must assume that the length, breadth, and depth of the basins were variable during the period of loading. It must assume that the neighboring lands were rising sufficiently to supply the agents of erosion with the material and the energy needed for gathering and carrying such colossal quantities of rock débris. And, to the embarrassment of not a few ambitious theories, it must explain the mechanics of these assumed events.

It must explain as well each successive stage in the growth of mountain systems. What was the source of the terrific compression that buckled the sediments in the basins as though they had been squeezed by the jaws of a mighty vise? How much of their present elevation is due to this lateral pressure, how much to vertical movements that elevated

such chains as the Alps and the Rockies long after the paroxysms of buckling had subsided? What was the rôle of the liquid rocks that rose to the breach when the hills were upheaved? Because the answers to these and many another related question are hidden in the depths of the earth's interior, there is as yet no adequate theory of mountain building. But there is a start towards one, and it marks one of the most brilliant crusades of the human mind in its campaign against the unknown.

V

The combined ingenuity of modern physics, chemistry, mathematics, and geology has opened a trail into the very heart of earth. It has opened to the human mind a vista of knowledge that the most ardent explorer of a century ago could never have pictured even in his dreams. Though clouds hang heavy on the scene, though some objects are etched but dimly and others not at all, the light of a new dawn is spreading into the caverns of the nether world. How much of that light will reach the deeper recesses of the realm, no one as yet may say. One may only perceive that each year the light is advancing a little farther and growing a little brighter.

Not so long ago it was generally believed that

the earth was a ball of hot liquid rock encased in a relatively thin and unstable crust. With cooling the interior was thought to shrink; the crust to crack and buckle as it sagged, like the skin of a drying apple, to the measure of the diminishing core. Today this view must be altered. Science has proved not only that much of the earth is solid, but that it may actually be gaining more heat through the decay of radioactive minerals than it is losing through radiation.

By measuring the force with which the earth attracts a precisely determined quantity of matter, physicists have computed the total weight of the globe and its average density. The mutually corroborating results of many investigators have established the fact that the earth as a whole weighs a little more than five and a half times as much as an equal volume of water. Similar methods have proved that the crust is considerably lighter than the average of the whole, a little more than two and a half times as heavy as an equal volume of water. The inevitable inference from these facts is that the deep interior must be considerably heavier than the average of the whole. No one knows whether the increase in density towards the center of the earth is due to the enormous compression of ordinary rock, or to the presence of heavy metallic minerals. Many

geologists favor the hypothesis of a density stratification from the surface downwards, with successively heavier shells around a core consisting of nickel and iron.

Careful measurement of the speed of those earthquake waves that pass through the body of the globe proves conclusively that rigidity as well as density increases with depth. Especially revealing are the transverse or distortional waves. Such waves cannot travel through a liquid, yet they move freely and with gaining speed to a depth of approximately eighteen hundred miles. Beyond that depth they become abruptly fainter, and in doing so suggest the existence of a core whose composition must differ decidedly from that of the shell or shells which surround it. In the half light of present knowledge the nature of the core is vague, but there can be no doubt that the outer zones are for the most part as rigid as steel.

Thus essentially solid, the earth is strong. It has shown its strength during the long and oft repeated ages when its surface remained sufficiently stable for the forces of erosion to grind vast tracts to flatness. But the earth is also weak, and has shown its weakness in the writhings of the crust. Progressive and perhaps periodic shrinkage of the globe through time is the only reasonable cause of the tre-

mendous lateral compression in the tortured zones of the mountains.

Volcanoes argue that the earth is hot, but they fail to reveal the amount, the distribution, or the origin of the hidden heat. And neither volcanoes nor any other source of information can unequivocally show whether the earth as a whole has been losing or gaining heat through the ages. The obvious shrinkage of the globe and its proved rigidity argue against the latter. Internal heat in the fulness of its power may have temporarily stayed the forces of condensation, but it has never stopped them. Whatever the geothermal condition may be or may have been, it would seem that the enormous pressures of the deep interior have ever worked to increase its density and decrease its volume; that gravity has consistently triumphed over every other force.

The behavior of earthquake waves as well as worldwide determinations of the value of gravity shows that the rocks beneath the oceans are somewhat heavier than those which constitute the continents. Whenever in the past the stresses of condensation have accumulated beyond endurance, both oceanic and continental segments may have sunk toward the diminishing central core. The heavier and larger wedges beneath the oceans must have sunk farther than the lighter and smaller wedges of

the continents, crowding them as the settling progressed. A moderate amount of such squeezing might have caused the gentle warping of the lands so prevalent in geologic history. Intense squeezing might have built the mountains by mashing the rocks in weaker zones. Relief of pressure might have liquefied materials below, and permitted them to rise in the various manifestations of vulcanism so common in the cracked and buckled belts of the globe.

This so-called wedge theory of earth movement, proposed by Professor Salisbury and the Professors Chamberlin of the University of Chicago, suggests in a general way the mechanism of lateral compression. The vertical movements that are known to have elevated many a range long after the convulsions of crumpling had subsided are still very largely mysterious. Determinations of gravity, however, strongly suggest a tendency in the earth to balance the lighter highlands against the heavier lowlands, the continental masses against the oceanic basins. As erosion stripped the former and deposited the débris on the latter, equilibrium in the crust was destroyed. The heavy segments grew heavier and sank farther; the light segments grew lighter and rose higher. Vertical foundering of the overloaded blocks forced deep-seated rocks to move horizontally by slow plastic flow, until balance was restored. That solid rocks

under pressure may flow like molasses is proved both by observation and experiment. But no one knows at what depths the balancing adjustments are made. No one knows how much unbalancing is needed to start the mechanism of equalization. Tendency to so-called isostatic equilibrium in the globe is as yet an undetermined factor in its history.

Thus along many battle fronts, the army of science advances on the strongholds of ignorance in the heart of earth. Speculations bristle like bayonets and collapse like papier-mâché. But though mistakes retard and darkness confuses, the army presses on. That it may sometime triumph is not for the present to say. Nor is it for the marchers to greatly care. Uncertainty is certainly part of the joy of walking in its ranks.

IX

Man's Biography in Stone

ALTHOUGH man has been on earth for more than a million years, his earliest adventuring is dimmed by the mists that settle over far horizons. Yet certain records do exist, and they reveal him not as a being just less than an angel who condescended to dwell among inferior surroundings, but as a creature somewhat higher than the apes who struggled towards a foothold in a shifty world. The early annals of humanity and the later annals of the earth are intimately interwoven. Indeed, during ages too remote and too lasting to be conceived through ordinary measures of time or remembered through ordinary documents, the biography of man like that of the earth beneath him is preserved in stone.

The bones of the ancients were flimsy, but their tools and weapons were of sterner stuff. The wear and tear of a million years have not destroyed them. When the continental glaciers of the Pleistocene surged over the middle latitudes, driving man and beast from their customary moorings and scattering them to every distant corner of the globe, primitive

men left a few bones and many artifacts amid the débris of geologic accumulation. In them lies the mute but eloquent story of man's first little victories in a hostile world.

The earliest artifacts were the crudely fashioned eoliths, "dawn stones" older than the oldest human bones as yet discovered. Around them has burned the fire of perhaps the fiercest controversy that ever raged in a field of learning which has known many a conflagration. Those who have believed in the authenticity of eoliths have believed enthusiastically. But science is suspicious of men with enthusiasms because such men tend to find what they seek—whether it exists or not. Nature is penurious with information about origins. It is her whim to obscure all beginnings. The nub of the difficulties that still confound the study of eoliths is the extreme crudeness of the stones, which in many cases makes it impossible to decide whether they have been chipped by accident or intent.

Even staunch believers admit that the shape of most eoliths resulted from buffeting by rivers and other forces of nature. Man merely retouched the products of natural workshops. Because the retouching is so difficult to distinguish from similar effects produced entirely by inanimate agencies, such a modern authority as Marcellin Boule has felt justified

in consistently opposing the theory of eoliths. Other authorities, notably George Grant MacCurdy, have consistently upheld it. The latter see under the roughness of these stones clear evidence of a rudimentary human industry, earmarks to distinguish the true eolith from its natural counterpart. Even the lay observer can see that, rough though they are, these stones fit the human hand and possess one edge sharp enough for cutting. Since the first alleged eoliths were discovered there has been much digging at the roots of man's family tree. Hard work and the passage of time have yielded many specimens, some no doubt but intriguing lies, others perhaps true relics of the dawn days of human handicraft. Science moves ponderously, but it has been clearly moving toward acceptance of the eolith.

This acceptance, had it come suddenly, would have smitten the human mind as sharply as did Darwin's revelations on evolution. Even if authenticity is denied all eoliths older than Pliocene, those from that epoch are old enough to double ordinary estimates of the duration of man's sojourn on earth. They establish an age in human history half a million years long, equal to the succeeding Paleolithic, Neolithic, Bronze and Iron Ages combined.

They tell of days when men stood still, when progress as we conceive it now did not exist. During

the five hundred thousand years of the Neolithic Age men seemed dedicated to the belief that since life can be maintained simply, it is foolish to invent complications. Throughout the entire age industry was almost static. Hammer and knife were the first tools used by man and the only ones he deemed necessary during the larger part of his early history. These he found ready-made in the fragments of flint supplied by nature. When use broke the hammer, he merely picked up a new one from the ground. When the knife's edge grew dull, he chipped it to a fresh sharpness. If either did not fit his hand, he hacked them crudely to shape. Invention lagged with the lagging of human needs. To the very end of the age, industry remained largely the improvisation of natural stones for simple uses. Eolithic man was obviously not interested in the perfection of machinery. There are those of his descendants who see some virtue in the ancient apathy. The Eolithic Age undoubtedly had its inconveniences, but there is no indication that among them were unemployment, market crashes, and starving children.

II

Man would not have been man had he not eventually felt the desire for things he did not possess.

Before the end of the Eolithic Age he learned to adapt special tools to special uses. There can be no doubt that human hands fashioned the flint tools and weapons of the following Paleolithic cultures, that imagination and the sense of need had at last awakened in the slowly dawning mentality of men. Invention was quickened and flints, roughly chipped into scraping, boring, and planing implements, were added to the knife- and hammer-stones of the preceding age.

Floors of late lower Paleolithic workshops have been unearthed in England. They were covered with thousands of flint implements and flakes, practically unaltered since the day they were hewn. They record the first climax of human attainment. Man was still an amateur in the art of living on the ground, still a weakling in a world of mighty beasts. But despite ceaseless struggle against the forces that surged about him, he somehow found time to improve upon the natural tools and weapons that had been his first meager defence in the new environment. He had become a hunter of quality, although inferior in strength and ingenuity to the saber-tooth cats with whom he lived and from whom he no doubt suffered injury and not infrequently death. He had discovered fire and perhaps a simple use of language. Before the termination of the lower Paleolithic Age

of stone, human beings had spread widely over the earth and had laid foundations for the future.

The middle Paleolithic brought significant changes. Three times Arctic ice had swallowed the upper portions of the continents of the northern hemisphere, and three times it had disgorged them. Once again ice was fated to fall upon the haunts of men, but not before the Neandertal race had established itself in western Europe. Though the Neandertals were men who buried their dead with reverence, they still bore the mark of the beast. They walked with an ape's stoop on stubby legs. Their large heads held large but primitive brains. Brutality lay in the brow ridges that met across the forehead, in the projecting teeth and the retreating chin. Unlike their predecessors who lived in open camps, the Neandertals took to the shelter and protection of caverns. Their remains are widely known in many lands. Preserved with their bones are the flint tools and weapons that record their craftsmanship.

Just as the preceding culture marked the first culmination of human industry, the Neandertal signalized the first retrogression. All through the earlier years of the Paleolithic Age, slow but undoubted progress characterized handicraft. The latter workmanship of the Neandertal race was clearly

decadent and in being so presents the first noteworthy proof that human history does not record an unbroken climb to perfection.

Perhaps the crowding of men in caverns tended to dwarf not only physique but also invention and technical skill. The Neandertal method of utilizing stone differed from all previous methods. The earlier workmen knocked the crust from nodules of flint and fashioned cleavers from the cores. Small implements were sometimes made from the flakes, but they never gained the importance or the excellence of the cleaver. The Neandertal workmen practically abandoned the cleaver and devoted their lesser energies to utilizing the flake. The cleaver slowly sank into oblivion, not because it had failed but because men had chosen the easier for the better tool.

The Neandertal race throve in the warmth of the third interglacial stage, but during the fourth and last glaciation of the Ice Age it foundered. Hard times and the coming of a superior race brought doom to the early cave men. The passing of the Neandertals marked the end of a chapter in the book of humanity, a chapter that told of primitive minds working largely in stone, and which scarcely suggested the rich and sudden flowering of human quali-

ties that was to come with the closing stages of the Old Stone Age.

The thorn in the side of evolution is the sudden and mysterious appearance of new types. Throughout the history of life new races have jumped into the record, races which like Topsy "just growed", their ancestry vague, even their place of origin undiscovered. Thus came the Crô-Magnon race to western Europe. Perhaps when the rock records of Asia and Africa are better known, the genesis of the Crô-Magnons will be revealed, but until then these men must be accepted as they first appeared to the western world: immigrants from the unknown.

The replacement of the Neandertal by the Crô-Magnon race and culture was the profoundest alteration the course of history ever underwent. The Neandertals were more primitive than the most primitive living race; the Crô-Magnons were equal if not superior in physique and intelligence to the most civilized. Parts of Russia, Scandinavia, England, and Holland were still buried under the ice of the last continental glaciers when the Crô-Magnons arrived in Europe. They settled chiefly in the Mediterranean lands where climate was salubrious, easily dispossessing those Neandertals who had survived the return of glacial conditions, and probably hastening the complete demise of that ill-fated race.

The Crô-Magnons are the first of the modern men. Since their appearance some thirty thousand years ago, the history of mankind is a fairly continuous record.

In 1852, a laborer found a rabbit burrow in a spur of the Pyrenees near the village of Aurignac, France. His curiosity was somehow aroused. He dug into the burrow and discovered that it led to a cavern whose entrance had been buried under rock débris broken off and rolled down from the hill above. Further excavation revealed a sepulchral grotto almost filled with human bones and closed to the world by a slab of limestone. It did not occur to the mayor of Aurignac that the bones might be priceless relics of an unknown past. With the congenital stupidity of his kind he ordered the skeletons —no less than seventeen, and of both sexes and all ages—to be given Christian burial in the parish cemetery.

When the anthropologist, Lartet, arrived some eight years later, the bones were decayed beyond recognition. Science could only guess at the geologic age, race, and culture of the people they commemorated. The terrace in front of the cave, however, told an important story through the carved bones of animals and the many flint implements it contained, the story of human beings whose industrial and artis-

tic attainments were far superior to those of any other race known to prehistory. Later similar artifacts, together with the remains of the Crô-Magnon men who made them, were exhumed in other localities. Seventy-five years of search have yielded so much information that the Crô-Magnons are better known today than certain obscure tribes still in existence.

Like their predecessors they were predominantly haunters of caves. Their industry was essentially a stone craft, although ivory from the mammoth and horn from the reindeer were extensively utilized. The cleaver and scraper of early Paleolithic cultures were replaced by blade-like implements made from flakes of flint. The flint graver, a small flat implement with a sharp edge at one end for engraving bone, ivory, and rock, was as typical of late Paleolithic cultures as was the cleaver of early. That gift of the gods, the creative impulse, had at last been given to men, and the graver was the first instrument for its expression. With it as a foundation, the human spirit first lifted itself above the meanness of a materialistic world.

The Crô-Magnons invented a new category of tools. Their rapidly growing aesthetic sensibilities gave birth to the arts of sculpture, engraving, and fresco, examples of which are now well known through the exploration and writing of the anthro-

pologists. The creative vitality of these people is exemplified not only in their art but also in the implements that made possible their art. The flint flake was modified to a variety of shaping tools for the manufacture of all sorts of objects of art and ornamentation. It was made also into instruments of less exalted purposes, some of sufficient delicacy to bore eyes in bone needles. Both types testify to a superb workmanship, at once meticulous and inspired.

With the end of the Paleolithic Age all art and industry decayed, for the talented Crô-Magnons faded from Europe as mysteriously as they had appeared. Stagnation and decline, which followed the first, crushed even more completely the second great industrial climax in human history. Such is the pattern approved by the sadistic heart of nature. Though industry and art were to rise again, stone was shorn of its glory. Never in the future was it to provide men with more than a secondary medium for the fulfillment of their practical and spiritual needs.

III

Certain cultures known as Mesolithic bridged the gap between the Paleolithic and the Neolithic Ages. The arrival of true Neolithic cultures in western Europe some twelve thousand years ago did not com-

pletely terminate the stone industries that so long had been one of the chief attributes of man. The Neolithic, in fact, is sometimes called the New Stone Age. But this appellation stresses the elements that linked Neolithic cultures to the past, without suggesting those that prophesied the future.

Although stone industry waned in the Neolithic, oddly enough it was during this age that a revolutionary method of working stone was evolved. In Paleolithic times men shaped their implements and weapons by chipping, afterwards polishing certain types for special purposes. This method survived well into the Neolithic, so that it is not always easy to distinguish late Paleolithic flints from those of the early Neolithic. Although chipped stone artifacts occur in all Neolithic cultures, it is the implements that were shaped by a new method of polishing without any preliminary chipping that best typify the stone industry of the age.

With the passage of time a great variety of cultural elements were introduced into the records of European races, so that it is difficult to correlate the stages of development in one country with those of another. The Neolithic history of Scandinavia is perhaps best known. There the early stage is characterized by the kitchen middens, dump heaps containing shells, bones, and many articles of human

handicraft. It is estimated that such an accumulation at Meilgaard originally contained over one hundred thousand artifacts. With the stone implements, in this stage shaped entirely by chipping, occur pieces of crudely fashioned pottery, articles of bone and stag-horn, and ornaments made from teeth.

The next stage is marked by the polished stone axes so typical in all countries of the middle Neolithic. The final stage contains a great number and variety of well made axes and hatchets, as well as chisels, saws, and hammers. To demonstrate their excellence a modern Dane once built a block house with Neolithic tools. Companioning the flint tools of the final stage are the flint weapons: spearheads, knives, poniards, and those uncompromising judges of Neolithic debate, the skull crushers. Perhaps the most impressive relics of the time are the stone graves known as dolmens. Most were built of massive rocks placed on the surface of the ground to form one- or many-chambered crypts. Loam was used to fill the chinks and in some cases to cover the entire structure. No sepulchers have ever better embodied the terrible dignity of death.

The Neolithic brought new methods and a few new devices to the stone industry, but its chief contributions to the advancement of humanity were not made in stone. The races that replaced the Crô-

Magnons in western Europe replaced very largely the Crô-Magnon way of living as well. They abandoned hunting for agriculture. They began to cultivate food plants and to domesticate animals. They invented the textile arts of knitting, spinning, weaving, embroidery, net- and basket-making. Neolithic inhabitants of Swiss pile villages knew well the use of flax and wool, but not of cotton, silk, or hemp. The art of ceramics began in the Neolithic Age and the art of healing received its first considerable expansion. Discovery of the wheel revolutionized transportation on land, and the dugout canoe inaugurated navigation. The cult of the dead was well established, rooted as it is in the primal emotions of the human heart. Finally, when the discovery of metallurgy gave copper and bronze to industry, the old stone culture all but disappeared.

IV

Yet metals with all their versatility cannot do everything. The very civilizations that were fostered by metals developed needs that metals could not satisfy. These needs could be partially served by stone, so that a new stone culture began to rise before the old one had completely vanished.

When men lived solely by the chase, and moved

restlessly from one cave dwelling or open encampment to another in search of better hunting, they required only the simplest weapons and utensils. Because of its uniform hardness, strength, and abundance, and its wide distribution, flint adequately supplied all the needs of prehistoric industry. When men became farmers they ceased to be nomads, their dwellings grew more elaborate, the necessary appurtenances of life increased. The strong and easily worked bronze and iron replaced flint for weapons and implements, but these materials were neither sufficiently abundant nor suitable for houses, palaces, temples, tombs, and roads. While men were still finding new uses for the few metals they knew, and before the existence of most metals was even discovered, the common rocks and minerals began to find a place in the affairs of men that they had never enjoyed during the Stone Age.

The ancient sepulchers of Neolithic days established a precedent that has never since been abandoned. Civilization rose from the stolid earth but it clothed itself in earthen apparel. For ten thousand years men of all continents worked stone into their buildings. The Peruvian Incas were among the earliest masters of stone construction. They quarried blocks of rock that weighed as much as a hundred tons, hauled them more than twenty miles, and skill-

fully mortised them into magnificent edifices. Later in Europe, some of the noblest visions of the human spirit were embodied in cathedrals fashioned from stone. Today many kinds of common rocks and minerals find a multitude of uses. They constitute about ten percent of the world's annual output of mineral matter exclusive of water. As few other ingredients of modern civilization, they are blessed by universal availability and cheapness.

Such rocks as granite, which originally congealed from a liquid beneath the surface of the earth and were later bared to the air by uplift and erosion, are widely available in many lands. Strong, impervious to water, beautiful, these crystalline rocks are quarried for use in buildings, monuments, paving, curbing, and riprap. Certain related volcanic rocks are crushed for road metal, ballast, and concrete.

Consolidated sediments of ancient seaways have likewise been drawn to the service of civilization. The abundant limestones are widely used in buildings, and even more widely as flux to release metals from their ores. The Machine Age was delivered, in fact, through the midwifery of limestone. This rock is also used in the manufacture of sugar and glass, and in agriculture as an antidote for sour soils. It is the chief source of the lime used in mortar, in the tanning of hides, and in many chemical indus-

tries. So great is the demand for limestone that the annual tonnage quarried nearly equals that of iron ore.

Sand and sandstone have also found their way into many industries. Loose sand is needed for mortar and concrete, for molds in iron foundries, for the manufacture of glass and abrasives. Many an old brownstone house can prove that certain sandstones furnish durable building material. Clay and its consolidated equivalent, shale, are made into bricks, sewer pipes, tiles, road material, and pottery. The metamorphic slates are valuable primarily for roofing and electrical purposes, and the marbles for building, monumental and ornamental stones.

With the gradual elaboration of human existence, a great variety of substances have come into a great variety of uses. In addition to the common rocks and the indispensable fuel and metal minerals, many an humbler constituent of earth plays a not insignificant rôle in modern industry.

There are, for example, the fertilizer minerals, friends of the farmer and all who depend on him. A ton of wheat is said to rob the soil of forty-seven pounds of nitrogen, eighteen pounds of phosphoric acid, and twelve pounds of potash. The longer a farmland has been tilled, the more it is necessary

to replenish such mineral ingredients if the soil is to continue to yield.

In Chile between the coast range and the Andes lies the desert basin of Atacama where a decade may pass without a drop of rain. Spreading for many miles just below the surface, the nitrogenous "caliche" rock has for ages escaped the destructive touch of water. No one knows the origin of this richest deposit of nitrate on earth, but it seems likely that it was derived from a neighboring belt of volcanic rocks. By a strange whim of destiny this product of a barren land has been drafted to buttress the failing fertility of more favored regions. Many years it supplied invaluable food for the plants which in their turn fed the world, until the discovery of a clever method of extracting nitrogen from the air greatly reduced the need for natural nitrates.

Phosphorus essential to agriculture occurs on the islands off the coast of Peru where birds flock by the millions and their richly phosphatic droppings have accumulated to a thickness of thirty feet or more. In certain places limestones have been impregnated with phosphorus leached from such guano deposits. In other places limestones contain large quantities of phosphatic shells imprisoned in the rocks at the time of their formation. England, France, and the

United States control most of the world's supply of this material.

Germany, on the other hand, controls the potash, a fact that proved more than embarrassing during the late war to many growers of potatoes, cotton, tobacco, and citrus fruit. The great Stassfurt deposits represent the final concentration of mineral salts in an inland sea whose water vanished by evaporation. Among some thirty minerals laid down on the bottom of this ancient sea were the potash salts, twenty billion metric tons of them, enough to supply the entire world for two thousand years.

Sulphur is a mineral of steadily gaining importance in both agriculture and industry. Until 1904 the world depended largely on the vast and rich deposits of Sicily. Since then, thanks to the brilliant imagination of Dr. Herman Frasch, the United States has become the largest producer. In Texas and Louisiana, deposits of sulphur exist at depths from seven hundred to eight hundred and fifty feet beneath the ground. Instead of mining in the ordinary fashion, Frasch perfected a process whereby the sulphur is pumped to the surface with the aid of hot water and compressed air. This ingenious method and the crude methods still used in the Sicilian mines furnish the most startling contrast in the realm of mineral exploitation.

Man has ferreted out a host of other non-metallic minerals to serve his expanding needs. There is gypsum for the manufacture of plaster, and graphite for use in crucibles, lubricants, "lead" pencils, and many other products. There is barite for paint, borax for boric acid, asbestos for insulating and fireproofing, mica for a variety of electrical devices. And there are many, many others to which, if this were a textbook, several wearying pages might rightly be devoted.

V

Justice demands, however, that one of this horde be granted special consideration. Nobody has ever thought of naming an age in history for it, yet neither copper nor iron are as necessary to human life. Indeed, though few minerals are more abundant or more easily obtained, the need for it has dominated every age. In certain remote corners of Africa where it is scarce, a man is worth no more than his weight in it. It is, in fact, the only inorganic substance other than water and air that both animals and men must regularly use if they are to go on living. Humble yet mighty, cheap yet invaluable, salt is the unsung hero of the mineral kingdom.

Through the ages the ocean has taken in the

wastage of the world. Insoluble materials worn from the land have gathered in layers on every square inch of its floor; soluble materials have mingled with every drop of its water. Some three and one-half percent of ocean water consists of solid matter in solution, of which seventy-eight percent is common salt. Joly once estimated that if the salt in the sea were concentrated, there would be enough of it to form a blanket one hundred and twelve feet thick over the entire surface of the globe.

Repeated warping of the earth's crust has repeatedly laid open the continents to invasion by the sea. Shallow bodies of marine water, like Hudson Bay, have many times swamped the lands since that forgotten day when they first presumed to lift their heads in the air. Whenever and wherever such inland seas have been cut off from the open ocean to perish beneath a desert sky, their ghosts have lingered on as deposits of salt. Many beds of rock salt originating in this fashion are inter-stratified with the sand, mud, and lime rocks of several remote geologic periods. Others of more recent origin occur on the floors of dead desert lakes and seas.

Not a few formations of rock salt are from three to four hundred feet thick. Several thousand feet of marine water would have had to evaporate to

form a bed of this thickness, yet where these deposits occur there is conclusive evidence that no such depth of water ever existed. As early as 1877, Ochsenius attempted to solve the riddle by imagining a relatively shallow body of sea water in a desert land shut off from the open sea by a bar. Evaporation would cause the saline ingredients, chiefly gypsum and salt, to drop to the bottom. Storm waves beating at intervals over the bar or tides pushing through it in narrow channels would replenish the water again and again, until a thick pile of saline precipitates had accumulated. Should such a bay ever evaporate completely, a film of potassium and magnesium salts would form.

This theory is as effective as any other in explaining such a thick series of alternating saline minerals as occur in the famous deposits of Stassfurt. But it fails to explain the thick accumulations of pure rock salt that are not associated with other saline minerals. At Wieliczka, Poland, is a strange underground city with a network of streets, a cathedral, a restaurant, a railway station, and a ballroom one hundred and ninety feet high—all carved in a gargantuan vein of absolutely pure salt. The city is marvelous enough, but the occurrence of such a colossal mass of unadulterated salt is both marvelous and mysterious.

If this deposit had formed in a lagoon as Ochsenius imagined, one would expect it to include not only a variety of saline minerals but also an abundance of fossil remains of animals that had suffered the misfortune of being swept into the foul waters. Karabugas Gulf on the east end of the Caspian Sea is a large lagoon separated by sand spits from its parent sea. An inlet a few hundred yards wide only partly replenishes the waning waters of the gulf, which evaporation has rendered somewhat more than twenty times saltier than the adjoining Caspian. Hordes of fish carried over the bar perish when they enter the bitter bay, and their carcasses are entombed in the salty sediments that settle on the bottom. Some are heaped in windrows along the shore, so profusely that the gulls, according to Andrussow, "feed only on the eyes, and do not even take the trouble to turn over the fish to get at the other eye."

Branson has suggested that if such a lagoon were separated from the ocean by two or more intervening lagoons, fossils as well as limy sediment would be deposited in the first depression with preliminary concentration of the water. Overflow into a second basin where further concentration would be effected might result in the precipitation of gypsum, which drops from sea water when thirty-seven percent has evaporated. In similar fashion, overflow into a

third lake might result in sufficient evaporation (ninety-three percent) to cause the precipitation of salt. Repetition of overflow and evaporation in the third lake might build up a thick unfossiliferous bed of pure rock salt, comparable with the deposit at Wieliczka.

Most ancient deposits of salt are less pure than the Polish ones, and consequently more easily explained. The modern world furnishes abundant suggestions as to their modes of origin. Pools of concentrated sea water form along many coasts. With recurrent invasion by the ocean, mud, gypsum, and salt are deposited in alternating layers. In other places arms of the sea have been entirely severed from the open ocean. Imperial Valley in southern California was cut off from the Gulf of California by the great delta of the Colorado; fossiliferous sediments and salts of various descriptions record the death of its waters in the desert sun. At not a few places the brines as well as the deposits of such trapped seaways have been buried beneath the sediments of subsequent accumulation. Many oil wells have tapped their hidden waters and much commercial salt is garnered from them.

Currently expiring lakes of desert countries also supply men with not a little of the salt they require. Evaporation of sea water in artificial lagoons pro-

vides still more. Little utilized as yet, the most remarkable of all salt reservoirs are the giant domes of Louisiana, Texas, and Germany. Squeezed from some hidden source deep below the surface, salt has gathered in columns that may measure as much as fifteen hundred feet in thickness and more than a mile in height. These saline monoliths became plastic with the writhings of the earth and pressed towards the surface, shattering and arching the overlying rocks as they rose. Should need ever develop, they could supply the whole world with salt.

Howsoever high the spirit of man may rise, he will never become independent of salt in one or another of its multiform occurrences. Nor will he ever escape some need of many another crude earthen substance. It is these that first gave him life, and through all his years have helped him to maintain it. With them he has written his own biography. Flint alone remains to tell of the earliest and longest epochs of his adventuring, but similar materials have outlined the events of every succeeding chapter. And when his struggles are finally done, when the structures he has built have moldered, when art and flesh have returned to clay, stones and minerals will yet remain. They may tell as of old their story of mankind, if perchance there are any who may care to listen.

X

Aristocrats of the Clod

THE story of man's progressive mastery over the earth he inhabits is in no small measure the story of his ingenuity in turning minerals and rocks to special uses. From the Stone Age to the Machine Age these materials have gauged progress in practical living. But making a living has never been quite all of living. Quaintly enough, certain minerals and rocks have gauged the emotional vagaries of human thought and conduct just as surely if not as completely as certain others have gauged man's progress in practical affairs. Love of the beautiful and the rare, fear of God and the devil, hope for special advantage, vanity, envy, and greed are abundantly illustrated in the attitude of men toward those aristocrats of the mineral world, the gem stones. The history of gems is also the history of the human heart.

Exceptional beauty combined with durability and rarity are the qualities that make gems from ordinary minerals, a trinity of virtues but seldom granted the inorganic children of nature. Many of

the most beautiful minerals are too weak to bear the stress of existence in a lady's ring, or even in her necklace. Some are easily scratched, others tend to break along planes of cleavage inherent in their molecular construction. Despite their softness, a few minerals—notably malachite, coral, and amber—have won to the hearts and to the persons of the fair. Gold and pearl, though weak, are highly prized for their beauty and rarity. On the other hand fluorite, which may be as beautiful as sapphire, and gypsum, which may have the sheen of pearl, are spurned both for their weakness and their abundance.

A few minerals with both beauty and durability fall in esteem merely because they are too plentiful. A fine garnet may be lovelier than a second-rate ruby, but no woman would care greatly to possess the garnet, unless perchance it be mistaken for a ruby. Blue-green beryl may be as beautiful as the sea, but fine aquamarines are too common for any status higher than semi-precious. Yellow and pink beryls may be very beautiful too, but they lack the rarity of good specimens of green beryl, the chief quality that has made the emerald one of the most valued stones of all ages.

The magic that transforms ordinary mineral matter into precious stones is as remarkable as the

magical powers so often attributed to such stones. All gems are daughters of the clod, special varieties of common substances. Carbon is the basis of coal and of the bodies of plants and animals; it is present abundantly in the air, the oceans, and the rocks; yet only under the rarest conditions does it occur with the purity of diamond. Corundum is a very hard oxide of aluminum, freely scattered through the crust of the earth. It is usually an unlovely brown, but sometimes it is blue sapphire, worth as much as $500 a carat. More rarely it is red, and when the shade is that known as "pigeon's blood," rubies may cost as much as $5000 a carat.

Why some minerals should possess the rare qualities of a gem is a riddle as difficult if not as deadly as the riddle of the Sphinx. The superiority of gems over their less comely relatives lies largely in their color. The color of some of them is inherent in their chemical constitution. All minerals containing large quantities of metal are of this kind. They have definite and unvarying colors. If these colors are sufficiently beautiful, as in the carbonates of copper—malachite and azurite—the minerals enter the gem class.

Many minerals gain color through pigment that grew into them as an impurity. Most of the finest gems owe their beauty to the impurity of their par-

ents. Quartz, for example, is ordinarily a colorless transparent substance, but when finely disseminated particles of iron or manganese oxides are scattered through it, the purple amethyst is born. The pigmenting impurities assume zonal arrangement in some agates and tourmalines. In other cases the impurities are coarse, as in the moss agates of Montana with their tree-like growths of black manganese oxide.

The color of many gems is caused or enhanced by certain optical properties. The opal gains beauty because it is shattered by many small cracks that break down the white light as it passes through. This results in a constant play of color similar to the rainbows on the surface of a soap bubble, but deep inside the gem. Qualities of luster and transparency, in some cases the result of highly complicated relationships between light and mineral structure, underlie the beauty of many jewels. Such stones are more readily enjoyed than understood. Why mere light and the ordinary stuff of the earth should mingle to produce the beauty of a gem is no more easily comprehended than why equally ignoble materials mingling in the head of a man should produce an appreciation of beauty. The problem belongs to the metaphysician.

II

The modern woman wears gems because they are beautiful, rare, and valuable—and because in many cases they are tokens of her sexual attractiveness, pleasant even after the signified quality has disappeared. Nobody knows exactly what motivated the earliest interest in gem stones. Some anthropologists maintain that it was belief in their magical powers. Others hold, perhaps more reasonably, that mere brilliance and beauty of color were enough to capture the attention and eventually the concern of primitive man, just as bright baubles give pleasure to certain animals and to all infants.

Howsoever an interest in gems may have first been aroused, it certainly took hold on the human imagination long before the birth of Christ, long even before the production of the first crude literature. Several thousand years ago gems were cut and carved in Babylonia. They were highly esteemed in the Egypt of the Pharaohs. No subsequent epoch in any land has lacked widespread concern for precious stones.

The nature of this concern has not been uniform through the ages. Beauty, fashion, and vanity have not always established the status of gems. Indeed, during most of the past, it was largely their supposed

magical, religious, and medicinal powers that commended them to their admirers. Supernatural qualities were early attributed to them. They became the dwelling places of potent spirits that might influence the lives of men and women. They were supposed to possess diverse planetary attractions as well as affinities for special virtues. They were worn variously: as amulets to drive away evil, as talismans to bring supernatural benefits to the wearer, as natal and zodiacal stones to protect children against special dangers inherent in the month of birth.

At a time when the whole world believed in miracles, faith in the supernatural power of precious stones was easy enough. Today the blessed sense of absurdity helps people escape such neurotic emotional fancies. Much of the past was not so fortunate. During the Middle Ages few questioned the unearthly influence of gems, and even during the Renaissance when reasons for such strange phenomena were sought, there was little tendency to doubt the validity of the phenomena. Rare indeed was the ironic sophistication of a certain fourteenth century court jester. When asked the property of turquoise, he replied that if a man with a turquoise on his finger should fall from a tower, the turquoise would remain unbroken.

Symbolism replaces ideas because the human heart is not moved by abstractions. Death, patriotism, and love in the abstract mean little; but a crucifix, a bit of cloth with stars and stripes painted upon it, a photograph of a dead friend, may stir deep feelings. Just so have precious stones been used as symbols. An ancient legend of Persia conceived jewels as concoctions of the devil. Satan, whose business is to lead men into sin by their appetites, observed that Eve loved the flowers of Eden. He invented gems, and through these flowers that never wilt, humanity was sown to greed and covetousness. Precious stones became symbols of these vices. But the philosopher who decries the folly of egotism usually signs his name to the article in which he decries it, and men have loved jewels knowing well that love of material objects is the mother of avarice and sorrow. Consistency has never been man's most conspicuous trait.

Only a shadow divides symbolism from superstition. The sign of a good or an evil easily becomes the good or the evil itself. Folklore is full of curious beliefs about gems. Every imaginable power has been attributed to them. The individual character of the stone is usually the basis for beliefs that grow about it. The diamond, for example, is hard, clear, pure, and it endows the wearer with

somewhat corresponding virtues: strength, fortitude, and courage. Ruby glows with everlasting fire which may burn out the evil from the mind and body of him who wears it.

Gems have been allowed not only talismanic powers of great extent but quite human idiosyncrasies as well. George Frederick Kunz in "The Curious Lore of Precious Stones" quotes this charming bit of anthropomorphism from the French writer, Mme. Catulle Mendès: "I have a ruby which grows dull, two turquoises which become pale as death, aquamarines which look like siren's eyes filled with tears, when I forget them too long. How sad I should feel if precious stones did not love to rest upon me!" The same author quotes from Sir John Mandeville's intriguing observations in unnatural history: "They [diamonds] grow together, male and female, and are nourished by the dew of heaven; and they engender commonly and bring forth small children that multiply and grow all the year." Happily for the jeweler but sadly enough for the prospective bridegrooms of the modern world, diamonds have discovered birth control.

If all were known about current beliefs regarding precious stones it might be difficult to exonerate the present from the foolishness of the past. A curious and not too admirable minor concern of modern

commerce is to supply Africa with agate amulets for counteracting the banefulness of the Evil Eye. Even highly civilized people cherish their superstitions, for example, in the popular fear of the opal as a gem of ill omen. Oddly enough, the opal was once considered the happiest of stones, combining the virtues of all other gems as it combines their hues.

III

Once the supernatural qualities of gem stones were generally admitted, their widespread use in religious ceremonies became inevitable. They were buried with the dead as passports to heaven. They were draped about and inserted in the statues of gods. With customary anthropomorphism they were sometimes given as votive offerings. That which was most beautiful and valuable in the mind of the worshipper was naturally thought most pleasing to the worshipped. The mound builders of North America destroyed enough pearls by fire before the images of their divinities to break the more secular heart of modern femininity.

The custom of engraving stones with sacred writings is lost in antiquity. The Egyptians were first to engrave hearts and scarabs of gem material with excerpts from the Book of the Dead. Passages de-

scribing the travels of a soul through the kingdom of the dead were read at funerals, and the engraved stones were hung upon the necks of mummies to protect the soul in its new adventure. Similar customs have been practised by other races and at other times. Desire for immortality, offspring of man's greatest despair and his greatest hope, is one of his special distinctions in the living world. There is a felicity in its symbolization through so many ages by the most distinguished members of the mineral world.

The religious imagination, desiring superlatives of grandeur, has frequently called upon precious stones. The New Jerusalem of Revelations, the Devârâka of the Hindu Puranas, the gem city of the Islands of the Blessed described in Greek literature, were richly studded with jewels. The Koran tells of a Fourth Heaven composed of precious carbuncles. Mundane temples strove after the richness of the mythical architecture. According to Garcillaso de la Vega in his "Histoire des Incas," the Spaniards found the Peruvians of the city of Manta worshipping an emerald as large as an ostrich egg. On feast days the Indians flocked in with gifts, especially with emeralds, daughters of the goddess. The priests, perhaps moved not entirely by the desire to appease the divinity or to beautify the temple,

did not allow their congregation to forget with what warmth of family feeling the goddess welcomed her offspring. In the end the Spaniards took most of the loot, only to lose much of it by testing each emerald with crushing blows. It was their stupid conviction that genuine stones could not be broken.

Scarcely less fanciful than the superstitious and religious usages of precious stones were the medicinal purposes to which they were applied. It is true that early Egyptians used lapis-lazuli in eye salves and hematite for reducing hemorrhage and inflammation, obviously aware of the astringent properties of such minerals and their therapeutic value in certain ailments. Very soon, however, the innate tendency to accept easy fancies rather than to work for more difficult facts asserted itself. Some of the quaintest of all lore concerns the technique with which be-jeweled medicine was administered by weak-minded physicians to weak-bodied patients.

A therapeutic color symbolism grew into accepted doctrine. In the belief that like cures like, red stones were used for blood diseases, yellow stones for biliousness. Stones green with the restful shade of the fields were administered for ailments of sight. Those whose blue was that of the sky were given as tonics against the spirit of night. Amethyst, whose very name was derived from a Greek root meaning

"to be intoxicated", was hurled with all the violent ineffectiveness of modern legislation at the hoary defection of Bacchus. For many years the best medicine for no matter what ailment was held to be that containing the greatest number of minerals of supposed curative powers. The receipt for an infallible cure-all survives from fifteenth century Venice. It is for a concoction of over thirty ingredients, including jacinth, topaz, emerald, ruby, pearl, garnet, coral, sapphire, amber, and several organic substances. No doubt it had the power to quiet a patient.

IV

The interest in gems persists today, but its nature has changed. There was a time when lovers sought the emerald as a talisman with power to reveal the true feelings beneath the actions of their loved ones. Today they cherish emeralds chiefly because they are beautiful, rare, and expensive—and because Princess Mary chose one for her engagement ring.

The desire for jewels, like many another human want, is not always proportionate to the means for satisfying it. When superstition set the value of gems, manufactured stones could not have found

many admirers. Even natural stones with slight blemishes lost some of their talismanic virtues. But now when beauty is the major criterion of a stone's excellence, the manufactured gem is not only acceptable but widely worn. To be sure, the best of the imitations are more abundant and far cheaper than their natural counterparts. Yet the modern woman of modest means prefers an imitation stone on her finger to a genuine stone that is out of reach. Besides, there is always the chance in an age of superficial judgments that the imitation may pass for the real. Even those who possess gems of great value not infrequently leave the true stones in the vault and wear their manufactured duplicates. If the Rolls-Royce is obvious the rubies are taken on faith, even though as likely as not they are products of the electric furnace, worth two dollars a carat.

The least valuable of all imitation gems are those that are made of a special glass known as paste. By mixing quartz, red lead, potash, borax, and a little white arsenic, a transparent, dense, and brilliant imitation of the diamond may be had. By adding pigments made from metals, stones of any desired color are easily manufactured. The mixture is ordinarily melted and poured into molds of required shape, but the better paste gems are cut as carefully as are natural stones. In one district in Czecho-

Slovakia more than twelve thousand people earn their living making glass imitations of precious stones.

Paste is softer than natural minerals, it breaks with the tell-tale curved surfaces of glass, and has different optical properties. Paste diamonds are less brilliant than real diamonds. Because of their lesser ability to conduct heat, they feel warm rather than cold to the touch. The quickest non-technical method of determining the validity of a diamond is to place a drop of water upon it. So different are the surface properties of paste and genuine diamond that in the former the water will spread whereas in the latter it will stand up in a globule. Those who have bought diamonds from cut-rate jewelers at "sacrifice" prices will in many cases be happier if they refrain from this simple test.

A more valuable type of manufactured gem is made by cementing together two stones to produce a larger one. A large stone is worth considerably more than two small stones even though it does not exceed their combined weight. Bits of diamond are frequently cemented together to form what is known as the doublet. Such fabrications are often ingeniously contrived, but they may be detected by certain optical tests, and usually by simply soaking the stone in chloroform or alcohol. These liquids

will ordinarily dissolve the cement and reveal the duality of the stone by separating the pieces.

False doublets consist of a piece of genuine gem stone cemented to a piece of glass or inferior stone of corresponding color. A slice of ruby may top a chunk of worthless paste, yet the stone may pass the usual tests, because its more exposed portions are genuine. Breathing upon such a stone will ordinarily reveal the line where the two parts join. Sometimes a colored liquid is inserted between an upper layer of quartz or some other hard, cheap, colorless mineral, and a lower layer of glass; sometimes colored glass or foil is used. Many an emerald is green because a layer of green paste has been inserted between layers of light-colored beryl or quartz. Many another, too pale to qualify as a gem in its own right, does very well in a solid setting lined with green foil. Deceit and jewels have always been bedfellows. In the past men easily deceived themselves, and in this day of skepticism mechanical ingenuity ably furthers the same end.

Some stones not quite beautiful enough to sell are made marketable by artificial coloring. Many agates consist of layers of varying colors, usually dull and unattractive. By soaking agate in a solution of honey or sugar, the more porous layers are made to absorb some of the sugar. An acid bath

will then char the sugar and darken the layers containing it, increasing the beauty of the stone by intensifying the contrast of its colors. Various other solutions are used to give agate a variety of vivid colors. Practically all agates, as well as many turquoises and opals, are artificially colored.

Yellow stones are a drug on the gem market. Topaz, which is usually yellow, may be changed to pink by careful heating. Some yellow diamonds may be whitened by radium, but the change is not apt to be lasting. Off-color diamonds have been coated with a blue dye that neutralizes the yellow tint. As with certain people, liquor reveals their true color. Alcohol dissolves the dye.

More respectable are the synthetic gems made chemically in the laboratory. Before the end of the last century, "reconstructed" gems built from fused particles of natural stone found good markets in several countries. Some of these concoctions were of fair size and color, but they had a disquieting tendency to burst into little pieces.

Diamonds can be made in the laboratory by dissolving burnt sugar in liquid iron. In the electric furnace under a temperature of 4000°C. the iron becomes saturated with the carbon of the burnt sugar. Upon sudden cooling in a bath of water, a crust of solid iron forms over the mass while the interior is

still liquid. Great pressures develop, which cause the carbon to crystallize, partly as graphite, partly as black diamond, and partly as microscopic crystals of clear gem stone. Other somewhat similar methods have yielded artificial diamonds with all the properties of natural stones. Unfortunately the largest one ever made was scarcely half a millimeter long, just a little better than visible to the naked eye.

Nearly a century ago synthetic rubies were made by fusing alum and chromium at a high temperature. For many years synthetic rubies practically identical with the natural gem have been produced on a commercial scale. Bits of powdered aluminum oxide and chromium are allowed to fall successively through the intense heat of a hydrogen flame, and the resulting globules to collect on a clay support. After a sufficient number of repetitions of the process, an artificial ruby of almost any desired size takes form on the support. Blue sapphires are made in the same fashion, merely by substituting a mixture of iron and titanium oxides for the chromium.

Such stones are nearly perfect counterfeits, similar to natural stones in composition, specific gravity, hardness, color, and other characteristics. They differ only in minor ways. They may, for example, show fine lines that betray their layered structure.

Their color may not be quite evenly distributed. They may have air bubbles and cracks not ordinarily observed in natural stones. Certain optical properties of the natural stone are less pronounced in the artificial—a mere technical difference. The only considerable difference is the price.

Yet despite the excellence of some manufactured gems they can never supplant natural gems in the human affections. Nobody would prefer the artificial to the natural gem if the two were equal in price. Even in an age that devaluates sentiment, sentiment still hovers round the genuine. Perhaps we have lived long enough with things that advertising insists are "just as good", but which we know are not. The best imitation of a precious stone may be nearly perfect in its mimicry, but it remains an imitation.

So it is that men still search the earth for natural gems—in Africa, Brazil, Siam, Germany, Burma, Colombia, Australia, British Guiana, Persia, the United States, Russia, Madagascar, India, and Ceylon. These countries, listed in the order of the value of their contributions, give up about eighty million dollars' worth of uncut precious stones each year. The darkest land yields the brightest gems, and the most valuable. Africa's diamond crop alone represents about ninety-two percent of the value of

the world's annual output of gem minerals. The sapphire runs poor second to the diamond, and trailing behind are amber, emerald, ruby, jade, turquoise, opal, rock crystal, beryl, tourmaline, and several others of less importance. Eighty million dollars is but a small percentage of the world's annual income, yet it is refreshing to find even that amount spent for a commodity whose chief value is natural beauty. Automobiles, radios, and bathtubs have not completely usurped the human soul.

XI

Time's Harvest

WHEN Venus rose from the ocean off the shores of Cyprus, she searched quite naturally for a looking glass. Her loveliness was full blown, and as she walked amid the terrestrial haunts of humanity, she longed for the mirror of the sea. Presently she acquired a piece of metal whose blushing brilliance reflected and even enhanced her beauty. So it was that copper came to be named from the island where it first gained importance in earthly affairs. Those who care to gaze today on copper's refulgent face, may see, like Venus, a picture of themselves. They may see, indeed, a picture of all mankind and its struggle for artistic and industrial expression.

Legend is careless of dates; one cannot be sure just when it was that Venus acquired her copper mirror. Nor is it certain just when the man who must have given it to her discovered the blushing mineral. The Egyptians knew it perhaps as early as 5000 B.C. Some authorities think it likely that the first chunk of copper used by man was in the native

state, uncombined with and therefore undisguised by other chemical substances. Certainly the glow of a piece of native copper might well have caught the Neolithic eye.

Discovery springs from the womb of curiosity. It is not difficult to imagine that the man who first found a specimen of native copper inquired into its properties. He probably tried to break it. On learning that it would not chip under his blows but flowed like a viscous fluid, he must soon have realized that here was better material than flint for weapons. It could be molded to a desired form more quickly and easily than flint could be chipped, and could be given a sharper edge.

Nature is not addicted to smoothing the way for her children. So effectively did she disguise the metals that man lived nearly a million years before he discovered them in any quantity. He could not rise above a stone culture so long as native metals were all he knew. The supply of these, however plentiful locally, was generally too scant to nourish an age of metal. Not until man had discovered the art of winning metals from their ores, of melting, casting, and alloying them to any desired shape and strength, could he claim a significant victory over the mineral world.

Necessity may be the mother, but accident has

certainly often been the father of invention. Sooner or later a chunk of copper or iron ore, in no way resembling the metals locked within, must have entered the circle of stones around some prehistoric hearth, to be reduced to metal by the heat of the fire and the charcoal of the embers. Sooner or later it must have occurred to observers that metals derived in this fashion were similar to the native metals already known. The discovery that liquid metal could be poured into a depression in sand to make an instrument or weapon of any shape might logically have followed. Thus the campfire probably gave birth to the art of metallurgy, and metallurgy sired in turn the successive cultures of copper, bronze, and iron.

Long have archeologists loved to debate the priority of discovery of their favorite metals. Although it is generally admitted that copper was probably not only the first native metal used by man but also the first one to be unlocked from its ores, there are those who maintain that the metallurgy of iron may have been known at an equally early period. Iron is more plentiful than copper and more easily smelted. The hill tribes of northern Nigeria reduce iron today without ever having known the use of copper or bronze. Iron rusts, and the earliest iron artifacts may have long since turned

to red powder, whereas possibly contemporaneous copper artifacts remain.

It is certain, however, that throughout the world at large, copper was the first metal in most general use; that even after iron appeared, it was utilized only as a substitute for copper and copper's chief alloy, bronze. Although the ores of this metal are restricted to certain localities, and many tribes must have been forced to go long journeys and fight hard battles for their supply, the discovery of copper smelting heralded the end of man's complete industrial dependence on stone. During the misty centuries between 8000 and 5000 B.C., the new knowledge was born and disseminated throughout Mesopotamia and Egypt, whence later it spread over central and western Europe. With it spread civilization, bearing culture in one hand and war in the other.

II

Nature has not been prodigal with her mineral treasures. She has hoarded them in small quantities through long ages. The farmer harvests a crop from his fields knowing well that other crops will grow in the future. The miner takes ore from the mine knowing that there is but one crop whose harvesting destroys the mine. There is a limit to

the amount of any valuable mineral within reach of man's acquisitiveness, and that limit is in many cases being approached.

Minerals form in various ways. Most of the metalliferous deposits were originally brought from the deep interior toward the surface of the earth in bodies of hot liquid rock. Some of them crystallized as segregations in the solidifying mother rock, but most of them were expelled into surrounding formations as gaseous or liquid solutions. Some disturbance in these solutions—by cooling or evaporation, by interactions with other solutions or with the enclosing walls, by changes in pressure—forced them ultimately to drop their precious freight.

Many of the richest ore bodies in the world have gathered about the margins of the intruding masses that gave them birth, either filling preëxisting pores and cracks in the invaded formations or settling in cavities eaten out by the parent solutions. Others traveled farther before coming to rest in the form of long tabular veins that filled the fissures through which their widely ranging solutions moved. Not a few deposits of this nature are rich enough to be profitably mined. In others the valuable minerals do not occur in sufficient abundance for mining until they have been concentrated by chemical or mechanical weathering of he rocks that contain them.

In all cases, the occurrence of metals near the surface is a violation of the law of gravity which orders the heavy minerals to remain in or near the central core of the earth. The rise of a few rebellious metals made an advanced industrial civilization possible. Because these constitute but a tiny fraction of the terrestrial rind they have bred no inconsiderable agitation wherever the emoluments of industry are loved more than its hardships, conflicts, and levies on the spirit are feared.

The history of metals in human life is more than the history of the gradual adoption of copper for tools and utensils, its subsequent replacement by the more durable bronze, an alloy of copper and tin, and later the general substitution for bronze of the still more durable iron. It is the story of the slow enslavement of humanity to its most effective servants. The early civilizations of Egypt, Palestine, Mesopotamia, Greece, and Rome were industrially no further advanced than modern China, largely because metals were not yet easily and abundantly available; but in philosophy, literature, art, and administration they were if anything superior to the civilization of the present. More recently, however, mining, manufacturing, transportation, commerce, and many other phases of industry have grown with the growth of metallurgy and the perfection of machinery. His-

tory since the fall of Rome deals very little with the improvement of the minds and hearts of men, and very much with the growth of that not so jovial Pantagruel of metal, the machine civilization.

Although many metals unknown to the ancients are in gaining demand today, the venerable copper and iron are still the most indispensable. When at the close of a relatively short age of bronze, iron replaced copper and its chief alloy in tools and weapons, copper sank so far in importance that for many centuries its chief use was in the manufacture of utensils for the kitchen. Not until after the middle of the nineteenth century did it rise once more in the esteem of men. When the world learned the use of electricity it discovered that copper was the cheapest good conductor. Modern life is dominated by power and light plants, telegraphs, telephones, and automobiles, no one of which could exist without copper. For roofing, plumbing, and coinage this metal is also widely utilized; and its alloys—chiefly brass and bronze—enact a thousand different rôles.

The exploitation of copper during the last dozen decades constitutes a romantic if sometimes sordid chapter in the chronicle of man's struggle for mastery over the physical world. By 1850, England relinquished to Chile the monopoly in copper production she had enjoyed since the beginning of the

nineteenth century. Although Chile held the lead for three decades and still harbors some of the largest reserves in existence, the real story of the development of copper is the story of its exploitation in the United States.

All the largest metalliferous ore bodies in this country lie west of the Appalachians. Copper was mined in Connecticut as early as 1702, but it was not until colonization had pressed considerably westward that Dr. Douglas Houghton discovered the vast deposits of native copper in the neighborhood of the Michigan city that now bears his name. The rocks of the region consist largely of an immense series of ancient lava flows and volcanic "ash" beds warped into a trough and jutting into Lake Superior at Keweenaw Point. Pure copper fills the gas cavities in the flows and cements the pebbles in the "ash" and conglomerate formations.

When Houghton arrived in 1841, he found abandoned mines that some unknown people had worked with implements of stone. By 1845, the new owners began mining in earnest and continued to expand their operations until the United States became one of the world's important copper-producing countries. In the early days great masses of solid ore exceeding one hundred tons in weight were encountered in veins. Forty men labored an entire year in the Calumet

mine to remove a chunk that weighed all of five hundred tons. Such large bodies of pure copper are no longer found but the region continues to yield a rich harvest, sufficient in fact to supply about one-tenth of all the copper used in the world. Some of the vertical shafts have burrowed more than a mile into the rind of the earth. They continue downwards for the end is not yet in sight.

Before the railroads opened the country beyond the Mississippi, prospectors had filtered into the remoter West on the scent of gold. Butte, Montana, was one of the earliest and blowziest of the temples to the yellow god. The gold soon petered out and the few miners who lingered after the boom turned to the silver. Among them was Marcus Daly, who, however, was interested in copper as well as silver. One historic day in 1880 he bought three lean gold-silver claims for a song, and proceeded to develop them into three of the richest copper mines on earth.

Eighteen eighty-one saw the coming of the railroad and the organization of the Anaconda Silver Mining Company. Such great bodies of copper ore appeared in the deeper workings of the company's mines that Daly forgot about the silver and in 1883 built a smelter to recover the copper. From then until his retirement Daly multiplied his millions and the district grew into the largest copper camp in the

United States and one of the largest in the world.

The Butte ores came into existence at the close of the reign of dinosaurs when a sea of hot granite rose from the deep interior and ate its way nearly to the surface before freezing solid. Ore-bearing solutions rose with it and filled the fissures in the cooling granite with compounds of copper, zinc, silver, lead, and other metals. They also altered and lavishly impregnated the surrounding rocks. Later, percolating waters leached copper from the upper portions of the veins, and redeposited it at depths of three to four hundred feet in a fabulously rich layer of chalcocite ore.

Today a thousand miles of burrows honeycomb the rocks beneath a modern Butte. In addition to a variety of other minerals which account for twenty-five percent of the value of the output, ten billion pounds of copper have already been extracted. Untold billions remain. At Anaconda twenty-five miles away, a hulking smelter daily ingorges unbelievable quantities of water, limestone, coal, coke, and ore. Its stack rises over a thousand feet above the ground in a futile attempt to diffuse its poisonous excretions. For miles about the country is as barren as a battlefield. And like a battlefield it commemorates the greed and lust that endow men with so peculiar a distinction in the animal kingdom.

In the seventies and early eighties the copper resources of Arizona, Utah, and Nevada began to compete with those of Michigan and Montana. Still later came the opening of rich lodes in Alaska. Finally, the discovery of immense masses of low grade ores and the invention of methods for utilizing them rendered Arizona the leading producer in a land that furnishes two-thirds of the copper needed by the entire world.

III

Despite the vast importance of copper in human affairs, iron is the real bread of industry. By 1000 B.C., every progressive nation on earth had discovered its worth and had begun to learn something of the art of hardening it for greater durability. Liberally distributed through the superficial rocks of the crust, this metal of a million uses is the very foundation of modern civilization. Should iron suddenly lose its capacity for assuming myriad forms, should its strength and magnetic properties suddenly pass away, chaos would fall upon the world of men.

Although iron has been widely used since men first generally recognized it as the best metal for weapons, tools, and utensils, the richest flowering of the Iron Age has taken place during the last hundred years. With the arrival of the railroads in the third

decade of the nineteenth century, iron came into its own. By the middle of the century, perfection of the Bessemer and open-hearth processes for making steel completed the raising of the curtain on the drama of modern machinery.

The setting of the stage occurred, on the other hand, long eons before man arrived to play the leading rôle. Since the dim dawn of geologic history, iron ores have been repeatedly born to different localities and in a diversity of ways. In the earth as a whole, iron is probably much the most abundant chemical element. Most of it is concentrated in the central core, but some five percent of the outer ten miles of crust consists of iron arranged in over two hundred mineral combinations. Of these, however, only four have any importance as sources of iron for industry. A few rare deposits of valuable iron minerals have originated as segregations in molten rocks that pressed upward from the depths of the earth. A few others are found near the margins of such intruding masses and are clearly the offspring of them. All the greatest accumulations, however, were laid down with the sediments of ancient seas, perhaps later to be altered and concentrated by percolating waters.

Such was the case in the Lake Superior district which supplies the world not only with much of its

copper but with more than one-third of its iron as well. Iron-bearing sedimentary formations of great antiquity extend in slightly elevated ridges not far south, west, and north of Lake Superior. In all but one of the ranges the rocks are crumpled and broken, and the ore bodies lie beneath the surface to depths as great as twenty-five hundred feet. In the Mesabi Range the rocks are nearly flat and little fractured. Only a thin layer of glacial drift covers the ore, which is removed by steam shovels from open cuts. More than half the iron mined in the United States comes out of the gaping maws of Mesabi.

The story of these deposits involves more than a billion years of history, for the rocks that enclose them are among the oldest known to science. They record a time of fret in the heart of earth. Deep beneath the surface, lakes of molten rock chafed at their confines. Vapors rich in iron and silica steamed from their surfaces and insinuated themselves into the overburdening formations. Working through to the floor of the continent which at that remote Pre-Cambrian Period was covered with ocean water, they dropped their cargo in the sea. After long epochs of sedimentation, deformation, and erosion, the silica was leached from the formations and large bodies of concentrated iron ore came into existence. Subsequent eons brought varied vicissitudes, but the de-

posits neither gained nor lost any considerable richness until man arrived in 1844.

Although every nation has its resources of this vital metal, iron has helped stain the land with human blood. The Lorraine district is the foremost producer of iron in Europe, and a breeding ground for conflict. At the close of the Franco-Prussian war in 1871, little was known about the nature of the deposits, but Bismarck was wise enough to move the proposed boundary of Lorraine far enough westward to include the surface exposures of the ore body. France, avid for gains on another front, agreed.

Knowledge increased with time. It was found that these so-called minette ores, like the ores of the Lake Superior district, had been laid down with sediments in continental basins of sea water. But unlike the Lake Superior ores, they had not been concentrated by later leaching, and as a consequence their iron content is some twenty to thirty per cent lower. Yet because they contain enough limestone to provide the necessary flux, because coal and a ready market are not far distant, they are exceedingly valuable. They were not workable, however, until 1879, when a process was invented for eliminating their relatively high per-

centage of phosphorus, the most destructive impurity an iron ore can possess.

Since that date the district has become one of the sweetest and least digestible plums in Europe's economic pie. It was soon discovered that whereas Germany owned the surface outcrops, most of the ore stretched under the surface into French territory. Thus it was that an innocent mineral provided one of the reasons beneath the excuses for the World War. France triumphed for the nonce when the Treaty of Versailles gave her the entire field.

IV

With spread in the use of iron came recognition of the value of many lesser minerals. In its most durable forms iron is alloyed with other materials, and the minerals that yield them are eagerly sought. Then there are lead and zinc, second only to iron and copper in the span of their utility. Although their ores occur in close mineralogical association, no two metals could differ more widely either in chemical nature or in the uses made of them. Ancient Rome used lead in pipes and solder; today most of this metal finds its way into storage batteries, cable coverings, paint, and buildings. Ancient Greece used zinc in the manufacture of brass, an alloy of zinc

and copper, but the major modern use of this metal is in galvanizing iron to prevent rusting.

Tin is yet another metal of ancient pedigree that performs a varied work in the modern world. The venerable bronze, alloy of tin and copper, is still in demand, but there is a greater need today for tin plate and solder. So lavishly favored in so many regards, the United States possesses much less than a just share of this metal. She fails to produce even one percent of the amount she consumes.

Few countries, indeed, are blessed with any large quantities of tin, for it is one of the rarer elements in the crust of the earth. Great Britain is an exception to the rule. Her Cornwall mines have been famous and lucrative since the Phœnicians sought them out a thousand years before the dawn of the Christian Era. The finest miners in the world labor deep in the granites of the Cornish coast. Bred to their task through centuries of rigorous selection they follow the veins of tin ore in the sternest of rocks, driving ever farther and deeper the channels of their sunken hive. In foul arsenical slime and terrific heat they hew to the industrial greatness of their native land.

Far to the east are men of a different color sweating in tin mines of a different kind. Stretching southward from Burma and Siam, through Malaya

to the islands of the Dutch East Indies lie the richest tin deposits in the world. Here nature has removed the ore from the stubborn rocks and has strewn it over the surface of the ground in alluvial gravels. The Chinaman with his primitive wooden water wheels, chain pumps, and sluice boxes is still conspicuous in the exploitation of these far-flung placers; but the white man with the more efficient dredging and hydraulicking methods of a newer civilization is rapidly replacing him.

Perhaps the most remarkable of all tin districts is in South America, sixteen thousand feet high on the slopes of the Bolivian Andes. Only dung and charcoal feed the furnaces in this land where water is frozen during half the year, and wind and lightning mock at the efforts of men. The lodes reach deep into the ground, and in more than one mine the ore is lifted to the surface on human backs, whence on the backs of mules and llamas it is carried down to the sea. But the richness of the ores offsets the rigors of the country and the crudeness of the mines. South America is second only to Malaya in the production of tin.

The can that brings food in a sanitary condition to the housewife was provided with far greater hardship than the pan in which she prepares its contents for the table. As likely as not the pan is aluminum,

a metal that constitutes about eight percent of the earth's outer crust, and is there more than half again as abundant as iron. It is indeed the most abundant of all metals and third most abundant of all chemical elements in the superficial shell of the globe, yet it lay hidden for centuries under a clever disguise. Not until 1855, in fact, was a commercially feasible process for extracting it invented. Since then it has come into such a varied and multitudinous usage that the twentieth century might almost be called the Age of Aluminum.

In every drama there are those who must play the lesser rôles, and the drama of earth is no exception. Many metals are too rare to rise above minor importance as individuals, yet in the aggregate they attain to no slight significance. There is antimony, for example, whose peculiar habit of expanding when cooled from liquid to solid renders it valuable in such alloys as type metal that must be cast with exceptional precision. There is mercury, liquid at ordinary temperatures and consequently useful in thermometers and similar devices. There is arsenic, so efficient in preservatives and insecticides; bismuth and cadmium whose distinction is the ability to lower the melting points of their alloys; magnesium whose lightness and durability make it desirable for a variety of purposes. And there are several others

which, each in its own modest but unique fashion, help turn the wheels of the modern world.

V

Thanks to the perversity and imagination of men, a few metals are valued more for their rarity than for any other attribute. Platinum, for example, is a hard, heavy, relatively insoluble and infusible metal about as abundant as gold. Most of it is mined in the Ural Mountains and in Colombia, South America, where erosion has removed it from the parent rocks and concentrated it in river gravels.

Because of its peculiarly resistant qualities, it early gravitated to the chemical and electrical industries. Eventually demand so greatly exceeded supply that it became several times as expensive as gold. It was then that fashion demanded it for jewelry. Even though it is no more beautiful than silver, even though certain cheaper alloys equal it in durability, platinum will continue to be used in mounting precious stones as long as it is expensive. Substitutes are already replacing it in several fields and perhaps it is destined in the end to sink back to the oblivion whence first it arose.

Silver and gold, on the other hand, though they possess no greater intrinsic worth than platinum, will

doubtless forever find a niche in the world of men. They are the traditional tokens of material wealth. Although the wisdom of using them as standards of value is no longer universally conceded, a large proportion of mankind will doubtless continue to endow them with this distinction. And even if they should be generally discarded as media of exchange, their beauty, durability, and rarity would continue to serve the needs of the heart and ego for art, jewelry, and ornamentation.

Alike in being major desiderata of human cupidity, gold and silver are alike also in another regard. They are frequently although not universally found together because both originated in lodes and veins that were introduced into the surface rocks by solutions working upwards from below. Although silver is at least ten times more plentiful than gold, both are sufficiently rare to be precious.

Silver is friendly to chemical union and is known in over two score mineral combinations. Gold, on the contrary, is a chemical lone wolf found chiefly in the native state. A large percentage of the world's silver is derived as a by-product of veins whose major values are in lead, copper, and zinc. At least one-fifth of the world's gold is taken from deposits of river gravels wherein native metal weathered from the parental veins has accumulated by

virtue of its superior weight, insolubility, and general indestructibility.

Love of gold infected the blood of humanity at an early date. Some archeologists believe gold the first metal known to man. Its untarnishing brilliance and its habit of crystallizing so frequently in the metallic state might easily have drawn attention to it before the discovery of the more abundant but more modest copper. Silver, on the other hand, usually hides its sheen in marriage with duller elements, and must long have lain unrecognized. By the birth of Christ, however, both were well known to the nations of antiquity, and had gained the strange hold on the imagination which they have never since relinquished.

The lust for gold reacting with the ferment of the human spirit has driven men to every far corner of the world; to every form of hardship, heroism and brutality. The yarns of the Marco Polos have been and still are irresistible. Columbus heard, then dared the western sea. Others quickly followed. Bewitched by the yellow metal, they drained the blood and broke the spirit of Mexico and Peru. Gold, in fact, provided the push behind every early exploration in both the Americas, and the chief reason for most of the colonization that followed.

For over three hundred years success eluded the

argonauts in the United States. Early in the nineteenth century a little gold was found in North Carolina and Georgia, but it was not until the pioneers had broken through the last frontier of the new land that they stumbled upon the real bonanza. On January 19, 1848, near the very end of the rainbow on the western slopes of the Sierra Nevada in California, John Marshall discovered the pot of gold. While building a sawmill on the south fork of American River he saw through the waters of a millrace the glint that was to dazzle the eyes of the world.

Before spring brought the first flowers to the Sierra slopes, news of the discovery brought the first miners. From Mexico, Peru, and Chili rose the initial swirl of a whirlpool that gained volume for two years and sucked into its vortex men from every land on earth. The Massachusetts farmer dropped his plough, the Australian herdsman abandoned his flock, shopkeepers from London to Rio de Janeiro emptied their tills and bolted for California. Over the plains in prairie schooners, around the Horn in sailing ships, through the pestilential forests of Panama, crazed with the dream of easy wealth they drove forever onwards. Some dropped in their tracks far from the land of their hopes; others ar-

rived only to die of exhaustion on the very threshold of success.

The story of those who survived is an oft-told tale. Many millions of dollars were washed from the golden gravels, enough to found a kingdom; but not enough, alas, to provide the weaker ones with their just share. Once in the poke, gold nuggets became as fluid as mercury. Fortunes won by day from the rockers and sluices were lost in the gambling houses and brothels at night. The average carpenter in the towns came through the boom with more money than the average miner on the claims.

In August, 1849, the quartz veins from which the gold in the placers had been derived were discovered and traced through a belt a mile wide and one hundred and twenty miles long: the famous Mother Lode. With the inevitable rapid exhaustion of the placers, activity subsided to a calmer exploitation of the veins, an activity that has persisted to the present.

Quite recently, indeed, rise in the value of gold has awakened the Mother Lode to a vitality that is faintly reminiscent of rosier days. Long deserted and forgotten camps have waked to the tramp of miners' boots, to the rattle of chips and the clink of glass. The faces and the faith of '49 are there again. Smooth-cheeked college boys and erstwhile

merchants mingle with the whiskered oldsters of the hills, comrades in a common hope.

Although the western slope of the Sierra Nevada has yielded some two billion dollars in gold, it is but one of several similar districts. The Comstock Lode deposits of silver and gold were discovered in 1858 at Virginia City, Nevada. The melodrama of rush days was played again; and again the anticlimax of exhaustion, of ghost towns moldering in the desert air. Eighteen seventy-six brought the Homestake Mine in the Black Hills of South Dakota, which even yet is perhaps the richest gold mine in the world. Eighteen-eighty brought the Alaska Juneau, known as the largest low-grade lode mine on earth. Eighteen ninety-one was the year of the opening of the Cripple Creek district in Colorado and 1896 saw the stampede to the Klondike. Tonopah, Nome, Goldfield, and others followed, bearing their gifts of wealth and heartbreak to men.

Elsewhere history has flowed in similar channels. At present the largest gold harvests come from the Witwatersrand district of South Africa, which in 1933 contributed forty-five percent of the world's production. Ontario, Russia, Mexico, Australia, and India all bask in the possession of enormous gold reserves; Mexico, Canada, and Peru have untold wealth in silver.

Few lands, indeed, are so poor as to lack some gift from the metalliferous heart of earth. Few, on the other hand, are so rich as to possess all the metals that modern civilization has decreed essential. Even the United States, most variously and generously endowed of countries, must yet import practically all its nickel, cobalt, platinum, and tin, as well as large quantities of half a dozen less important metals.

So it is that the search for new deposits goes on forever. The prospector blazes the trails of history, and lays the foundations of government, industry, and commerce. From the frozen deserts of the north to the steaming jungles of the tropics, from peaks that pierce the clouds to valleys that sink below the level of the sea, he follows his restless star. Glow of the yellow metal still fires his imagination and drives his body from the comfortable haunts of his fellows, but the lesser minerals are no longer entirely beneath his consideration. These the modern world must also have, and a dollar's worth of lead is equal in all but romance to a dollar's worth of gold.

VI

Lavishly in wind and torrent the earth has spent her powers through time. Yet so bountiful are her

resources that two billion profligate years have failed to stem the streaming of her vital energy. The second law of thermodynamics decrees that some day she too will die. Some day her restless soul will drift into the bay of eternal calm, the final harborage of every striving. But consummation of the threat seems no nearer now than in those misty epochs of the Pre-Cambrian dawn when first she began to record her history in the rocks.

Men who float like spars on the stream of her forces must move as the current wills. They are spars, however, with the rudder of intelligence, and have learned to go their hazardous way with ever decreasing hazard. They have even learned to control for their private delectation some of the lesser eddies of the flood. With the magic of their minds they have turned a portion of the wilding flow into slaves who do their bidding. Not only do stone and metal surrender their quiet strength, but the more turbulent children of Gaea yield a little to the persuasion of human ingenuity. The winds and waters abandon their aimless roaming to pump the wells and spin the wheels of man. And some of the latent forces asleep beneath the surface of turmoil have completely capitulated to his will.

Like other spendthrifts the earth indulges in petty economies. Chained in many a hidden dun-

geon are giants whose energies have outlived the imprisonment of eons. Only the earth may know why these alone among so many of her children should have been so carefully conserved. Man does not trouble his mind to learn the secret, for he has learned another secret more pertinent to his opportunist aims. He has discovered that under their years the giants have mellowed, that they will do his work without complaint.

Long ages ago, during a period now known as Pennsylvanian, the monotonous march of history underwent a significant change. Most of the United States stood close to the level of the ocean. Mountain ramparts guarded the eastern and southern borders, rolling plains reached far to the north. Disconnected highland barriers ranged down the Pacific Coast, and between them the sea made a way to the low-lying central basin. Slowly across Texas and Oklahoma the waters crept, until they gained at their peak Nebraska on the north and Pennsylvania on the east. Nearly one-third of the entire continent was theirs.

Transgression of the lands by wandering shallow seas is hardly exceptional. Earth history is very largely the record of such floodings, endlessly repeated with the restless shifting of the body of the globe. The Pennsylvanian seaways resembled a host

of others that enjoyed a vagrant heyday both before that time and since. They differed from most in the unusual conditions that developed along their eastward margins. There very early in the period the rivers that drained the flanking uplands dumped an untold tonnage of sand and mud. In what is now Pennsylvania, West Virginia, and Alabama, mighty deltas crowded back the sea.

With the nervous writhing of the continental platform, the water and the growing delta lands struggled to extend their domains at each other's expense. Sometimes the sea advanced to the foot-hills of the marginal uplands, sometimes vast swampy lowlands stretched far to the west. A tangle of fast-growing plants usurped the swamps with each evacuation of the sea; with each transgression they died in matted hordes and were buried beneath sediment brought down by the streams.

Vegetation rotting in modern swamps and bogs suggests the early adventures of the Pennsylvanian plants in the world of the dead. Living trees and grasses rise from the remains of recently deceased ancestors, and these in turn recline on the mold of earlier generations. This brownish black substance is known as peat, and is readily recognized as the condensed and decomposed remnant of vegetable material. It consists chiefly of carbon left behind

after bacteria have driven off some of the volatile carbon dioxide, marsh gas, and water. Along many flat swampy coastlines of today, where the moisture is sufficient both to favor a luxuriant growth of vegetation and to prevent the complete decay that follows death in the air, peat has accumulated to as much as forty feet in thickness.

In the far wider marshlands of the Pennsylvanian Period grew some of the greatest forests the world has ever known. Peat must have repeatedly accumulated to several hundred feet in thickness, as slow subsidence of the land kept each new generation of plants near the level of the water table. With burial of these bogs beneath the advancing sea, more of the volatile gases were vented by compression, and the peat was compacted to the brown woody variety of coal known as lignite. Further condensation raised the percentage of fixed carbon and altered the lignite to a slightly lustrous black.

Still further reduction of volume increased the density until the lignite passed into bituminous coal. Later, with the crackling and folding of the associated formations, more gas was locally ejected and the valuable hard, black, glassy anthracite came into existence. In certain phases extreme compression has ruined the coal by driving enough oxygen and hydrogen from anthracite seams to produce large

quantities of incombustible graphite. Nathaniel Shaler's classic comment was not entirely a joke. "Bury me," he said, "in a Rhode Island coal mine. It's the only place on earth that will not burn."

Coal has formed during every period in earth history since plants first learned to thrive on the land. But no other period has yielded so much high grade coal as the Pennsylvanian. Conditions were then exactly right, and since then enough time has elapsed to develop the more valuable varieties. Not only in North America, but also in Great Britain, France, Germany, and Russia, the richest coal beds are of Pennsylvanian age. Over a gulf of nearly three hundred million years they have brought the energy of an ancient sun to stir the modern world.

Humanity, so quick as a rule to utilize its blessings, was slow to discover the value of coal. The ancients knew its properties but preferred wood. Even as late as the seventeenth century, laws restrained its usage because it was dirty. Not until the invention of the steam engine, in fact, did coal come into its own. Rapidly then with the rise of mechanized civilization, it rose to such importance that water alone exceeded it in production, value, and demand. Miners in a million poisonous holes risked their lives for it while nations fought to control it. Today it is still the cardinal source of power the

world around. But its position is far from secure. Out of the underworld of rock has risen yet another sinewy giant, to menace the industrial supremacy of coal.

VII

When Noah calked his ark with asphalt, he was doubtless unaware of the symbolic significance of the act. He could scarcely have known that one day the world at large would calk a million projects with essentially the same material. He could not have foreseen that petroleum and its various products of distillation would eventually become the most useful substance on earth.

Nor could the other venerable pioneers in the discovery of this potent clan have divined the sequel of their knowledge. For centuries most men were satisfied to gaze upon the perpetual fires of burning gas seeps in the East, piously pondering the terrors of Hell. But others like Noah devised more practical usages. It is told of Medea that at the time of a religious festival she decorated a rival with an oil-drenched veil, and watched her burn to a cinder upon approaching the altar flame. Greek captains are said to have routed the elephant corps of Carthage by turning among them an unhappy band of blazing oil-anointed pigs. The Babylonians utilized

petroleum in their buildings, the Romans in their lamps. With it the ancient Egyptians preserved their papyrus documents against the depredations of time. They used it both as medicine for the living and as embalming fluid for the dead, so that pillaging Arabs of a later day found Egyptian mummies an excellent fuel. Thus began with modest ingenuity the mightiest industry of the modern world.

In stricter sense the beginning would seem to have been made by organisms far different from men, in days no human documents record. Although some scientists have argued an inorganic origin for petroleum, most have believed it, like coal, a legacy from living creatures. Unlike coal, petroleum is no child of the land. In some regions the two occur together, but in deposits of different age and origin. Because all valuable oil pools have been found in sedimentary rocks of marine accumulation, it is not reasonable to include land vegetation in the group of probable parents. Most experts agree that most of the available petroleum was derived from the decay of plants and animals that were both born and buried in the sea.

Petroleum is a substance of simple ingredients intricately united, a compound of carbon and hydrogen in a melange of gaseous, liquid, and solid solutions. Although under the microscope it displays its

blood relationship to such undoubted organic materials as sugar and lactic acid, it does not reveal the type of organism that mothered it. So widely scattered in time and space and so chemically variable are the natural hydrocarbons that doubtless many kinds of creatures were involved in their making.

Some authorities believe them chiefly the result of animal tissue putrifying at the margins of shallow seas. The oil of Galicia is found in formations so rich in the remains of fossil fishes that certain geologists believe fishes the most likely ancestors of the oil. Computations show that if only half the fat from the annual catch of herrings on the north coast of Germany were turned into petroleum, it would yield in 2560 years as much oil as Galicia has thus far produced. Elsewhere other types of animals suggest the probable source of the oil. In the Caucasian fields the petroleum flows from rocks that entomb the shells of myriad molluscs. Along the bays of the Red Sea where animal life abounds, petroleum can actually be seen in the process of formation today, as scum on the surface of the water.

Other authorities consider marine plants the major source of petroleum. Masses of seaweed like those of the Sargasso Sea might sink to the bottom and generate petroliferous substances during their decay. Sheets of seaweed fringing the coasts of

Sweden and Sardinia give off an oily material resembling petroleum. In the San Joaquin Valley of California, the salt water associated with the oil pools is unusually rich in iodine, an element which is likewise unusually abundant in seaweed. Furthermore, in the oil-bearing formations of eastern United States, the fossil remains of marine vegetation are lavishly preserved.

From these and a multitude of comparable facts it would seem that natural gas, oil, and asphalt might very probably derive either from animal or vegetable matter, or from both. F. W. Clarke thus neatly summarizes the problem: "Wherever sediments are laid down, inclosing either animal or vegetable matter, there bitumens may be produced. The presence of water, preferably salt, the exclusion of air, and the existence of an impervious protecting stratum of clay seem to be essential conditions toward rendering the transformation possible. Seaweeds, mollusks, crustaceans, fishes, and even microscopic organisms of many kinds may contribute material to the change. In some cases plants may predominate; in others animal remains; and the character of the hydrocarbons produced is likely to vary accordingly, just as petroleum varies in different fields."

VIII

Although this organic theory of origin is acceptable to most investigators, the biological and chemical processes whereby the carcasses of marine creatures became petroleum are vague and consequently debated. Many believe the oil a product not of death but of life. It forms in the living bodies of such simple plants as diatoms and algae, a tiny drop in each individual. With death and decay the oil is freed, and if the water is muddy, some of the droplets cling to particles of sediment and sink with them to the bottom. In this fashion through the ages, petroleum may have been interred at various levels in the hoarded heaps of sedimentary débris that constitutes so large a portion of the earth's surficial crust.

Those who believe petroleum chiefly the product of decomposition, assume that bacteria in search of oxygen attacked the sunken wreckage of water-dwelling plants and animals. Removal of oxygen liberated carbon and hydrogen from the decaying flesh. Some of this vented material united chemically to form methane gas, some to form oil which may or may not have been enmeshed in the mud. The more resistant fats and waxes became concentrated with escape of their volatile ingredients, to

be buried eventually beneath the mud. Very slowly the bacterial action continued, until large portions of the mass were altered to petroleum. Even today, after oil-bearing sediments have hardened to rock and eons have passed down the roadway of time, the ghouls are still at the feast. Professor Bastin of the University of Chicago found living bacteria in oil brought from three thousand feet beneath the surface of the earth.

Although at present it is difficult to evaluate these differing views, it is clear that in one way or another great quantities of liquid hydrocarbons may easily have accumulated during various periods of the past. The heat and pressure of deep burial and earth writhings may have aided the biochemical agencies in converting the organic waste into petroleum. With time and the compacting of the muds, the imprisoned globules of oil might readily have been squeezed together and forced to migrate with the movement of associated waters, or merely as the result of the different specific gravity of oil and water. Because of the light weight of the oil its movement would have been dominantly upwards. Where large-pored formations topped the mother sediments and were topped in turn by small-pored impervious formations, the petroleum would have gathered as in a reservoir.

So, at any rate it is found today. Oil migrates through a porous reservoir until stopped by some peculiarity in the architecture of the crust. Several different conditions have caused the trapping of petroleum in pools, but the upwarped rock wrinkles known as anticlines are both the simplest and the most generally effective structure. If gas is present, it rises toward the crest of the dome until checked by an impervious stratum. Lodged beneath the gas is the heavier oil, and beneath the oil the water.

For centuries few of these facts were known. Petroleum lay untroubled in its cave. Although it seeped to the surface in many places, no one suspected the priceless pools below. In 1595, Sir Walter Raleigh described the pitch lake of Trinidad and the excellence of the pitch for trimming ships. But as late as the nineteenth century, modern men had advanced very little beyond the ancients in exploiting any member of the petroleum family. Several brine wells in eastern United States yielded oil as an impurity, and some of this was sold as medicine. Generally, however, it was considered a nuisance.

By 1859, it became obvious that petroleum might easily compete as an illuminant with oil distilled from coal. Accordingly in that year a syndicate hired Colonel E. L. Drake to drill a well near an oil spring at Titusville, Pennsylvania. After heart-

rending delays and to the tune of sceptical laughter, Drake struck oil at a depth of sixty-nine feet. Suddenly the laughter turned to cheers and wild excitement. Wells were drilled everywhere. Petroleum flashed in the human imagination like a comet in the sky.

In half a century oil has risen from a curiosity to the most eagerly sought and most desperately needed substance on earth. As a source of energy it has outstripped water and it promises soon to outstrip coal. Some three hundred products of petroleum have already been pressed into a multitude of uses, and many others are destined to be developed in the immediate future.

But rapidly, too, it is vanishing. In 1920, David White estimated that about two-fifths of the oil reserves of the United States were already exhausted. Although no one can know exactly when the end will come, anyone can see that it must come soon. Possibly some day some effective substitute will be discovered. Just possibly, failing this, life may be found still good in a slower, quieter world.

The quest for energy, however, will never cease. Plants are content with the sun and the air, and the ordained level of their lives. Most animals are happy to dwell as parasites on plants. Men alone are discontented. They share their bones with the

tailless apes, and alas not a few of their feelings, but their ambitions are their own. Since first they learned to strike fire from the rocks they have striven for the conquest of energy. This is one of their chief distinctions in the universe, and will doubtless ever continue so while fire endures on earth and life in men.

Because of the erratic distribution of universally necessary minerals, trading in minerals has joined with prospecting as a major international pursuit. But trading can never appease the hungering of blind self-interest. In the past the treasures of earth have bestowed both the blessing of comfort and the curse of war. In the future they may just possibly bestow the blessing without the curse. Nobody can surely tell, because nobody can know whether the lusting of the beast or the dreaming of the god will eventually triumph in the human mind.

XII

The Limits of Freedom

THE earth is a selfish mother who would keep her children forever at her breast. Men alone among her multitudinous brood have dreamed of independence and have struggled to achieve it. The successes they have won have made them masters of the living world. They move down the avenues of their striving with heads in the air, not always remembering that their feet are on the ground. Basking in the warmth of self-esteem like turtles in the sun, they forget that they too are children of a jealous clod.

The earth, however, never forgets. While men are sleeping she is awake, silently strengthening the cords of her influence. When men make boast of their conquests she is not concerned, for she knows that the limits of human attainment are the limits she chooses to set. When they strut through the kingdom they think they have conquered, she tightens the strings that hold them to her hand.

The fabric of human life has been woven on earthen looms. It everywhere smells of the clay.

Even where men have triumphed most the mark of their manufacture is upon them. Modern civilization rose with the exploitation of rocks and minerals, but only through channels prescribed by the earth. The whimsical distribution of these valuable resources has not only fed the worms of national cupidity until neighbors have clutched at each other's throat, but it has bred fundamental differences in the very spirits of men. The work and thoughts of the Montanan are not those of the Mississippian. Their outlooks on life are different largely because nature gave metals to the one and denied them to the other.

Howsoever high the spirit of man may soar, the stomach controls the flight. It is on this organ that humanity, like an army, ever must advance. Beneath the stomach is vegetation, beneath vegetation the soil, and beneath the soil the ceaseless and varied turmoil of terrestrial forces. Every volcano that fumes to the sky, every erosive power that ramps over the prostrate body of earth, is a mill for the production of soil. Because both the grist and the grinding vary from place to place, agriculture must vary in accordance, and with it the fate of civilized man. For agriculture is the inescapable first concern of civilized man, and where soil is thin or poor, so-

ciety wilts; where it is deep and rich, society blossoms.

The industrial and social stratification of Alabama provides a perfect example of the influence of soil in human life. Behind the swamplands of the coast is a belt of sandy pine barrens. Much of the region is uncultivated because the soil refuses to yield; the scattered population is primitive and poor. Inland lies a second belt of deep black loam, beautifully suited to the needs of the cotton plant. The white men who own this land are prosperous; the cities are crowded and culturally advanced. Beyond, the fertile acres merge with a third belt of hills and reluctant soil where poverty, ignorance, and toil are the only dependable crop.

The haphazard forces of earth have determined not only the broad patterns of mining and agriculture, but in myriad other ways they have shaped the destiny of man. The Titans who sundered the globe into oceans and continents, and the lands into mountains and plains, sundered just as surely the lives of men. The Hollander with enterprises that span the seven seas is vastly different from the Tibetan who has not even heard that the seas exist. Should a Kentucky hillsman ever meet a Mesopotamian plainsman, language would not be the sole barrier

to mutual understanding. They differ as fundamentally as the lands that produced them.

Throughout most of the history of mankind the ocean has been a barrier to the easy intermingling of peoples, and consequently a challenge to ingenuity. The invention of the boat changed the direction of human evolution as profoundly as did the discovery of fire. Navigation freed the innate wanderlust of the spirit, and vastly extended the reach of exploration, colonization, and commerce. It threatened every stronghold of provincial seclusion the world around. Today, with the help of aviation, it has all but made good the threat.

The fortunes of mankind have shifted like sand along the coastlines of the world. Swarming like hungry ants from their barren peninsula the ancient Greeks settled on many a distant shore. The Germans did the same in Russia, and the Swedes in Finland. In the Philippines, successive invasions of Malays crowded the native people far into the hinterland. In western Scandinavia, on the other hand, the usurpers drove the original inhabitants to the coast and kept the hinterland for themselves. Thus today the two abide—the short round-faced brunette Norwegians of the coastal lands, and the tall, longheaded blonde Swedes of the interior.

In countless ways the sea has seeped into the lives

of men. The restless forces that have shaped the coastlines of the world have indirectly shaped the people who inhabit them. In such mountainous lands as Japan, where farming is difficult, the traits that color an entire nation may be born along the shore. Usually, however, coastal and inland people are quite unlike. The sea and the pursuits of the sea have molded the philosophy of the dwellers on the strand; intermingling with immigrant tribes has molded their physique.

Even more significantly have the lands beyond the coasts directed the course of human evolution. Man is a terrestrial animal. The sea gypsies of the Sulu Archipelago, who live and die in boats and whose only arts are sailing and fishing, lead lives that would hardly be universally appealing. Even these nomads of the deep must sometimes come ashore. In burying their dead on the islands and never in the sea, they symbolize the inescapable union of men with the clod that mothered them.

Physiographic variations of the land have everywhere varied the lives of the inhabitants. Mountains, for example, are islands in the sea of civilizing forces because life is hard where slopes are steep and winters cruel. The wild tribes of Afghanistan are valid children of the rugged wilderness that bred them. Even in less remote places, mountain-

eers, while sturdier than plainsmen, are less educated and more provincial. All great civilizations have flowered in the lowlands. Most urban centers of culture today, like their withered forbears of yesterday, have grown on plains of gentle relief. There nature yields most readily the bounty of a heart that is none too generous at best, and allows mankind the surplus energy which is indispensable to its higher aims.

So it is that the forces that molded the earth have likewise molded humanity. The freedom men love to boast is too often but clever adaptation to conditions that no man is free to change. Civilization is held to the earth. Although it may fly over many an obstacle, it must ever return to its rocky roost.

II

Beyond the immediate tyranny of terrestrial forces is the greater tyranny of the cosmos. The earth is a member of an ordered society whose Master does not brook caprice. With monotonous fidelity it has ever abided by the laws that were decreed in the beginning. Because of these laws, it possesses a definite size and weight; it spins on its axis and goes its journey around the sun with definite speed and direction. And man, who must fol-

low the earth wheresoever it may lead, must bend to the earth's limitations. His very stature and strength are a response to the size and weight of the globe, to the unyielding pull of gravity; his lungs and heart are a response to the air which gravity holds a prisoner. His rest and work are geared to the earth's rotation and revolution, to the endless succession of days and nights, the ceaseless rhythm of the seasons. The same inexorable necessities, in short, chain both the earth and man. Both are cosmic slaves.

Yet both are allowed a strange uniqueness among the shoals that swim the sea of space and time. The diameter of the solar system is actually billions of miles. Were it but a single mile, the star nearest the sun would lie about seventy-five thousand miles in the offing. The average distance between the other stars in the galaxy of the Milky Way would approximate this order of magnitude. In a disciplined universe of such vastness and relative emptiness, the chance is not great that any two stars should approach closely enough to disrupt each other by mutual gravitative attraction. Yet of so slightly probable a catastrophe the earth was probably born. Equally slight was the chance that the earth should have taken a course some ninety-three million miles from the sun, and have intercepted as a result just

one two-billionth of that star's radiant energy. Yet from this contingency the atmosphere and liquid water came to be, with their gift of turmoil to the rocks. Temperatures on most of the globe were held to the range that lies between the freezing and the boiling points of water—a meager pasture in the pampas of the universe at large where they may run from the $-459°$ F. of space to the $10{,}000°$ F. of certain stars. And out of all these conditions together came life, rarest of all the varied wonders of the world.

The age-old struggles of the flesh have culminated in the spectacle of man. Like the oyster, man yearns for comfort in a hostile world, but he yearns in a fashion peculiar to himself. His longings, once fondly thought to be proof of an immortal soul, persist even now when he may no longer properly assume that a soul exists. Whatever it be called, there is something in man that is not content with the satisfaction of the mere biological urge to live. In reaching for the moon, though he may never obtain it, he achieves the ultimate uniqueness.

The obstacles in the path of his desires are not solely the restraints of the world he inhabits. His greatest handicap, indeed, is the body he inhabits. And his greatest problem is the problem of the nature and control of vital energy. Solutions depend

on an understanding of materials and forces that are essentially the same in roses, angleworms, and men. They depend, in other words, on an understanding of that universal living jelly which biologists call protoplasm. Although the object of intensive study for several decades, protoplasm unfortunately is still largely the enigma it has always been. Although its ingredients are known and easily available, the ultimate character of protoplasm is still the greatest mystery of the living world.

The chief reason why this mystery has endured when so many others have gone down to defeat is that any very searching analysis changes protoplasm from the condition described as alive to the condition called dead. Its strength to defy science lies in its delicacy. Behind this wall many of its riddles lurk, and nothing that science can do will lure them out into the light. A scientist must view protoplasm as a man on a mountain views the varied structures and activities of a city on the plain below. But unlike the latter, who may descend for a closer examination, the scientist may enter the inner precincts of protoplasm only by destroying it. He may see it through the haze of distance or he may scrutinize bits of its wreckage, but in either case he may gain no very clear conception of what it is or how it works.

The problem is further confused by the fact that protoplasm in the abstract does not exist. It exists only in extremely small units called cells, whose structure, activity, and relationship with other cells and with the environment are extremely complicated. The opening decades of the twentieth century have been marked by perhaps the most intensive pursuit of biological research in the history of civilization. Most of this research has been focused on the cell, yet the key to its inner secrets has not yet been found.

Men have today a scarcely more fruitful conception of life than had their ancestors; they have a no more acceptable explanation of its origin; out of their knowledge of the changes that protein undergoes they can mold the activity of living creatures but little nearer to the heart's desire. It helps very little that this mother mystery of life has given rise to a howling brood of lesser mysteries. When science gives chase to these—such for example as the problems of the origin and control of disease and mentality, or of the causes behind evolution and extinction—they always take refuge in the parental fog. Yet until at least these fundamental problems are solved, it will be difficult to guide either the individual or the race to any significantly happier adjustment with the world than it now enjoys.

III

Since the dawn days of life in the Archean Era, plants have been utilizing the radiant energy of the sun to manufacture starch and protein from air, earth, and water. For nearly as long, animals have been elaborating vegetable material into the albuminoids and proteids which, chemically speaking, constitute their chief distinction. Modern biochemists have succeeded in duplicating with raw mineral material several of the processes and structures and some of the substances of plants and animals. But the most brilliant chemists have utterly failed to produce a complete living creature, because they can neither repeat nor understand much of what even the simplest bacteria and protozoans have been doing for more than a billion years.

Perhaps the world is no loser because scientists cannot create life in the laboratory. The womb of nature is sufficiently fertile for all practical purposes. It may be trusted, as long as the earth remains reasonably friendly, to supply all the creatures that anyone might desire—and a great many more. Yet the same tangle of enigmas that trips the scientist in his attempt to create living protoplasm also prevents him from directing protoplasm to many of the goals of which men dream.

Of all the sciences, medicine faces most squarely the basic mysteries of the flesh. Although death still comes to men as inevitably as ever, the fight against disease has gone forward not without its triumphs. Indeed, the practical accomplishments of medical science are so radiant that the eye is all but blinded to its failures. Its successes have devolved very largely from the discovery of how to retard certain diseased conditions in the march to their lethal goal, for such a time as nature may need to restore the affected tissues to health. The failures of medicine, which unfortunately are quite as numerous as the successes, devolve from the abysmal ignorance of what lies behind the immediate causes of disease. These ultimate causes, even of the controllable diseases, are just as mysterious now as when the first skin-clad shaman dug off the top of a man's skull to free an imprisoned devil.

And problems of disease, baffling though they are, are simple when compared with the problems of human mentality. The power of thinking, feeling, and willing is the most striking characteristic of man. Through it, but without consciously directing it, he has already risen to the headship of the animal kingdom; through it, by conscious direction, he hopes to obtain far more. But of all his attributes, mentality is the most complex and variable, the most

difficult to understand not only in its manifestations but in the causes behind the manifestations. It constitutes the tightest tangle of problems in his nature. Yet he must unravel the tangle and straighten each thread before he can find the way to his cherished goals; before he can learn either how to be thoroughly happy as an individual or thoroughly progressive as a species.

The venerable enigma of mind and matter persists. The modern psychologist has restated without resolving it. The higher forms of mental activity elude his cleverest measuring devices as surely as they eluded the mystic of old. He has helped explode the deep-rooted concept of the dualism of body and soul by demonstrating the error of viewing the physical and mental aspects of life as separable realities. But his new monism yields little of practical value. Despite their sophisticated patter of Freudian jargon, men must still pursue their reasoning and their remembering, their loving and their fearing, in the dark. Knowing neither what these are nor whither they are driving, men must pursue them without directing them just as did their forefathers for a million years or more. Far ahead lie the slopes of Olympus which they would like to climb. They feel that somewhere not nearly so far

away is the secret of the ascent—but they know neither where nor how to look for it.

Control of disease and mental reactions is the crying need of individual men. The problems of this control might all be solved so that a man could learn to harvest the full crop of his latent powers, but unless the powers as well as the capacity to use them may be increased, man as a species cannot progress. There was a happy day when men believed that the advantages an individual gains for himself might be handed down to his offspring; that the fruits of the strivings of one generation might become the inheritance of the next. Perhaps the most discouraging discovery of modern science was that inheritance in the legal sense does not exist biologically, that many of the most valuable attributes of an individual are not heritable. Mark Antony was right in more ways than he could have suspected when he said that the good is oft interred with the bones.

Men run in wide gamuts of variation from the weaklings to the Samsons, the dolts to the Einsteins, and the criminals to the saints. Thousands of variations arising in the environment seem to leave no lasting mark on the species because they do not affect the germ cells which alone can transmit the traits of human nature. It is pleasant to feel that no matter

how bad the father, the child need not necessarily be predestined to the same fate. It is not so pleasant to realize that the excellencies a good father has acquired may be of absolutely no biological advantage to his children.

It is blighting to know that the causes of Mendelian combinations and mutations, which seem to be the true vehicles of evolution, are utterly unfathomed. The secret of self-directed human progress lies buried in the bits of germ plasm that geneticists call genes. Yet geneticists have not the vaguest conception of how to alter a specific gene to produce a desired specific result. With all their knowledge of the mechanics of reproduction, heredity, and evolution, they cannot tell how to breed either better individual men or a better race of men.

Accordingly, the light of day brings harsh and narrow limits to the dream of perfecting humanity. Men may strive through education and environment to alter advantageously their individual glands, nerves, muscles, and brains; but they may not hope to reach the germ plasm with such alterations. They must swallow the chagrin of the realization that such alterations in themselves can be of no direct help to their children; that there is no certain method of insuring for their offspring the advantages they have won for themselves. They must also

accept as happily as may be the fact that some of the more deeply rooted traits and tendencies in the germ cells are bad, and that they are no better able to withhold these than to bequeath their painfully acquired virtues. Men may, in short, give their children such an assorted parcel of good and bad characteristics as was given them, and hope that the children may find for themselves some satisfactory solution to the problems of life.

There are those who believe that even if the future biological development of man must be left largely to imponderable blind forces, his social development will still be in his own keeping. Like property, culture and civilization are passed from generation to generation quite independently of the germ plasm. Why might they not wax onward to perfection?

They have not yet done so simply because men have not yet learned how to profit from the experience of others. There is no more certainty that a rich civilization will transmit its richness than that a successful father will have a successful son. There is almost a certainty that the opposite will be true because the germs of social no less than of biological decay are numerous, lusty, and treacherous. Inheriting socially the advantages of previous civilizations, men inherit as well the blight that removed

them. In the declining birth rate among the higher classes, in the amalgamation of races towards the production of a common type, and in many less significant ways, the modern world is reënacting ancient tragedies.

It would seem indeed that dust to dust is an inexorable and universal injunction of nature. Death in one form or another hovers over every endeavor of the flesh. Unnumbered dynasties of living creatures have walked such paths of glory as the gods allowed—to the same inevitable end. The causes behind the extinction of races constitute the most elusive of all life's mysteries because they are the slowest in producing their effects. No one has the slightest conception of their nature.

Individual men and civilizations are children of the fickle earth who bred them, the earth who suffers the flowers to bloom and die, the mountains to rise and fall. That a better fate is in store for man as a species, no one can surely know. No one, indeed, need care. Even though the swirl of unavailing cycles engulfs him, even though the abyss of extinction may lie beyond the horizon, there is yet joy in the journey. For man is the only animal who can face with a thought, a dream, and a smile the mystery and the madness and the terrible beauty of the universe.